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1963

VOLUME II

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BUREAU OF COMMERCIAL FISHERIES

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VOLUME II

3646)
(25-48)

Family Elopidae[1]

SAMUEL F. HILDEBRAND[2]

Characters. Body slender, more or less compressed laterally; belly rounded; ordinary scales covering median line. Eye large, with adipose tissue in large examples. Mouth large, terminal, or superior. Maxillaries large, in about three pieces, extending far beyond eye in adults. Premaxillaries not protractile. Lower jaw with an elongate bony plate between its branches. Teeth all small, often bluntly villiform; teeth present on jaws, vomer, palatines, pterygoids, tongue, and basibranchials. Branchiostegals about 23–35. Gill membranes separate, free from isthmus. Opercular bones with membranous borders. Gill rakers moderately long. Last several segments of Spinal column directed upward toward base of upper lobe of caudal. Lateral line present. Scales large or small, with membranous borders; missing on head; the median row in front of dorsal neither enlarged nor modified. Dorsal fin over or somewhat behind pelvics. Caudal forked. Pectorals and Pelvics similar, each with a rather long axillary scale.

Remarks. The members of this family are characterized by the presence of the bony gular plate between the arms of the lower jaw, the numerous branchiostegals (23–35), and the large terminal or superior mouth.

The genera *Tarpon* and *Elops* (pp. 112, 123) sometimes have been assigned to two families, Megalopidae and Elopidae. However, the two genera agree in so many seemingly basic characters—the gular plate, numerous branchiostegals, the dentition, the large maxillaries, and the primitive character of the caudal skeleton—that it seems desirable to treat them as one family.

The members of the Elopidae generally are considered to be among the most archaic of existing teleosts. Their antiquity, particularly as indicated by their skulls, has been fully discussed (ftn. 3).

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[1] Edited and emended by George S. Myers, Henry B. Bigelow, and Yngve H. Olsen.

[2] August 15, 1883–March 16, 1949.

Reprinted from Memoir Sears Foundation for Marine Research, I (3), 1963: 111–147

The young pass through a leptocephalus stage, similar to that of the eels.

Range. The members of this family are widely distributed in the warmer seas.

Key to Western Atlantic Genera

1a. Body moderately deep, rather strongly compressed laterally; mouth superior, with tip of mandible entering dorsal profile; last ray of dorsal and anal produced, filamentous; scales large, about 41–48 in a lateral series; anal with about 22–25 rays. *Tarpon* Jordan and Evermann 1896, below.

1b. Body very slender, not greatly compressed laterally; mouth terminal or nearly so; last ray of dorsal and anal not produced into a filament; scales small, generally more than 100 in a lateral series in American species; anal with fewer than 20 rays. *Elops* Linnaeus 1766, p. 123.

Genus *Tarpon* Jordan and Evermann 1896

Tarpon

Tarpon Jordan and Evermann, Bull. U.S. nat. Mus., 47 (*1*), 1896: 409; type species by original designation, *Megalops atlanticus* Cuvier and Valenciennes, Hist. Nat. Poiss., *19*, 1846: 398.

Generic Synonyms:

Clupea Bloch, Naturg. ausland. Fische, Pt. 9, 1794: 32; in part, for *C. cyprinoides* Bloch; Shaw, Genl. Zool., *5* (1), 1804: 173, for *C. gigantea* Shaw.

Megalops Lacépède, Hist. Nat. Poiss., *5*, 1803: 289; in part, for *M. giganteus* Voigt *in* Cuvier, Das Thierreich (German transl.), *2*, 1832: 423.

Characters.[3] BODY oblong, rather strongly compressed. VERTEBRAE about 55. PSEUDOBRANCHIAE undeveloped. BRANCHIOSTEGALS about 23. MOUTH quite oblique, superior, with prominently projecting mandible. LATERAL LINE decurved, with branched tubes. SCALES large, not especially primitive, their characters similar to those of *Elops* (cf. Cockerell, *17*: 122); scales extending somewhat onto base of anal and caudal but not onto dorsal. DORSAL fin high anteriorly, its last ray produced and filamentous. ANAL similar to dorsal but longer, its last ray produced in large examples, its origin not far behind dorsal base. PELVICS inserted well in advance of dorsal fin. Last several VERTEBRAE clearly out of line with main axis, being directed toward the tip of upper lobe of caudal. AIR BLADDER large and opening into gullet; within bladder a considerable amount of cellular, lung-like tissue; two large and two small strands adhering to bladder wall (bladder serving somewhat as an air-breathing organ, much as in gars [pp. 64, 67]; for description and figures of the modified bladder, see Babcock, *1* [1936]: 50). ALIMENTARY CANAL much shorter than body; the stomach large, reaching far back into abdominal cavity as a sort of blind sac, the two orifices rather close together. PYLORIC CAECA numerous, short and branched, held together by connective tissue.

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[3] The skull has been fully described and figured by Gregory, who regarded it as a little less primitive than that of *Elops* (*30*: 137–142, figs. 31–33). The characters of the tail of *Tarpon* and related genera have been described by Regan (*59*: 354), and in more detail by Hollister (*39*: 264).

Remarks. This genus is close to *Megalops* Lacépède, the oxeye herring represented by *M. cyprinoides* of the Indian Ocean and adjacent Pacific, but it differs from *Megalops* mainly in the more anterior position of the pelvic fins—well in advance of the dorsal fin in *Tarpon* but inserted under the base of the dorsal in *Megalops*. Thus the difference is in the position of the pelvic fins rather than in the dorsal as stated in the original description of *Tarpon*. Hollister, who compared specimens, has stated that *Tarpon* has only 57 vertebrae whereas *Megalops* has 68, and that *Tarpon* has 12–15 dorsal rays whereas *Megalops* has 19–21 (*42*: 449). Also, *Tarpon* grows to a much larger size. American ichthyologists generally have accepted *Tarpon* as a valid genus while Old World students have rejected its separation from *Megalops*. Perhaps in consideration of the additional differences now known, the separation may seem better founded. Compared to *Elops*, *Tarpon*'s body is not as slender, its scales are larger, and its dorsal and anal fins have long filaments attached to the last ray of each fin.

Species and Range. A single species is known, ranging from Cape Cod, Massachusetts, to southern Brazil. It has been reported also for tropical West Africa.

Tarpon atlanticus (Cuvier and Valenciennes) 1846

Tarpon, Tarpum, Sabalo Real, Cuffum, Silverfish, Silverking, Grand Ecaille, Jewfish, Palika

Figure 19

Study Material. A total of 25 specimens: 14, 78–1,175 mm TL (57–837 mm SL), measured in the laboratory, from Boggy and Boca Grande, Florida; Fajardo, Puerto Rico; "Cuba"; "West Indies"; and "Amazon River," Brazil; 11 adults, 100–1,990 mm TL, from Gatun and Miraflores locks, Canal Zone, examined for food, sex, and spawning condition.

Distinctive Characters. See *Remarks*, above.

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 14 specimens in the *Study Material* unless stated otherwise, specimens 57–837 mm SL.

Body: depth 23.5–29.
Head: length 25–31.
Snout: length 4.5–6.2.
Eye: diameter 5.3–9.5.
Maxillary: length 15.5–18.
Anal fin: length of base 18–20.
Pectoral fin: length 19–22.8.

Scales: 41–48 series.
Gill rakers: 19–21+36–40.
Fin rays: dorsal 13–15;
anal 22–25; pectoral 13 or 14.
Vertebrae: 53–57 (4 specimens).

Body with almost vertical sides; the dorsal outline of head nearly straight and horizontal, the back somewhat elevated, with ventral outline strongly curved anteriorly; depth 3.4–4.3 in SL. Scales large, firm, with crenulate membranous border. Lateral line complete, decurved anteriorly, the pores branched. Head moderately short and deep, its depth at middle of eye not quite twice its width at the same place, 3.2–4.7 in SL. Snout to rim of upper jaw considerably shorter than eye in small specimens, gradually becoming equal to and finally longer than eye during growth, 4.5–5.5 in head. Eye 3.3–4.7 in head, much nearer to dorsal than to ventral profile, wholly in anterior half of head in adults. Gill rakers rather long and slender, scarcely denticulate. Mouth superior. Mandible projecting far beyond the gape, entering dorsal profile in advance of mouth. Maxillary broad, strongly curved, extending under posterior part of eye in young (80–100 mm) but far beyond eye in large examples, 1.5–1.9 in head.

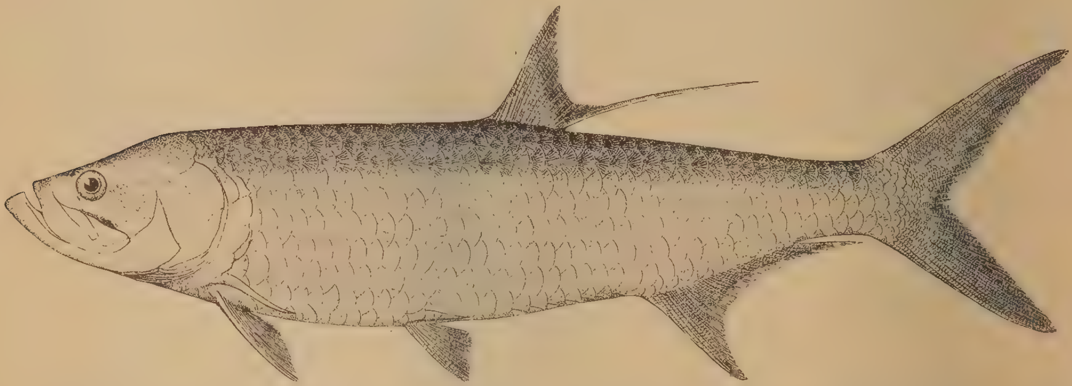

Figure 19. *Tarpon atlanticus*, from off New Jersey, USNM 14924; from Goode. Drawn by H. L. Todd.

Dorsal fin high anteriorly, its last ray produced in specimens over 100 mm long, quite long in large specimens, reaching to end of base of anal fin in some specimens seen; its origin about equidistant between base of caudal and anterior margin of eye. Caudal deeply forked, the lobes of about equal length, generally somewhat longer than head. Anal somewhat elevated anteriorly, its last ray produced in adults, sometimes reaching the base of lower rays of caudal, its origin at least an eye's diameter behind end of dorsal base, its base 4.6–5.6 in SL. Pelvic rather large, inserted more than an eye's diameter in advance of origin of dorsal, and somewhat nearer to base of pectoral than to origin of anal in large specimens. Pectoral rather long, extending to base of pelvic in small specimens, not nearly to pelvic in large ones, 1.2–1.4 in head. Axillary scale of pectoral rather small, only about a third of the fin length, 2.7–3.4 in head.

Color. Preserved specimens bluish silvery above, sides and lower parts bright to pale silvery. Pectorals and pelvics pale; other fins all more or less dusky. Longley remarked, "The large eye falls below the level of the dorsal green and its iris blends with the silvery side. As seen by the diver this great fish appears unsubstantial, a gray ghost floating in gray water" (*49: 5*).

Size. The Tarpon reaches a very large size; an individual a little over eight feet having an estimated weight of 350 pounds has been reported for Hillsborough River Inlet, Florida. A fish up to six feet in length, having a weight of perhaps more than 100 pounds, is not very rare.

Development. The exceedingly large number of eggs produced by a Tarpon indicates extreme prolificness. For example, a female 80 inches long, weighing 142 pounds (caught and reported by Babcock, *1* [1936]: 41), contained 12,201,984 eggs according to a close estimate made by John T. Nichols of the American Museum of Natural History. This great number far surpasses the classic example of the prolificness of the large codfish often mentioned, which contained 1,839,581 eggs.

Ovarian eggs, taken from both unripe and spent fish, measured 0.6–0.75 mm in diameter, a small size for so large a fish. They sank slowly when placed in sea water, suggesting that they may be demersal, not buoyant.

Tarpon eggs that have been spawned naturally and are positively identifiable as such have not yet been described, nor have the early stages after hatching. But it has been assumed from analogy with its smaller relative (*Megalops cyprinoides*) of the East Indies that the Tarpon, like the ladyfish (*Elops saurus*, p. 124) and the bonefish (*Albula vulpes*, p. 134), passes through a ribbon-shaped leptocephalus stage during its larval development. This assumption has been corroborated by the capture at Beaufort, North Carolina, of a leptocephalus 20 mm long, near the transition stage; this, from comparison with the corresponding growth stage in *Elops* and *Albula* (*35*: 45) and in the East Indian *Megalops* from Java, probably was a Tarpon.[4] (One 18 mm long, recently pictured and described by Gehringer, certainly was [*27*: 290].—H.B.B.)

The smallest fry definitely reported as Tarpon have ranged between 16 and 19.6 mm SL (*32*: 6, fig. 5, pl. 1; see also pl. 2 for fry up to 36–38 mm; for earlier accounts of 37 and 77 mm fry, see *13*: 229 and *63*: 72). Breder's painstaking study of extensive series of various sizes from the western coast of Florida has shown that little alteration takes place in the body proportions with subsequent growth.

Rate of Growth. Analyses of the number of checks on the scales of Tarpon from the western coast of Florida, where it may be assumed that growth is interrupted during the cold months, suggest that in open waters it averages about 3,050–3,060 mm in length at one year, about 510–640 mm at two years, and about 1,270–1,525 mm at three years. Earlier scale studies (*1* [1936]: 68) suggest that a Tarpon averages about 1,376 mm or four feet six inches when it is nine or ten years old, that a fish of 70 pounds is about 12 years old, and a fish of 100 pounds is perhaps 13–16 years of age.

Tarpon kept in the old New York Aquarium grew more slowly than those reported above, from less than 500 to only 1,220 mm in five years, perhaps as a result of confinement (*13*). Present indications are that a Tarpon does not ordinarily mature sexually until it is about four feet long, i.e. until after the sixth or seventh winter (*13*: 229–247).

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[4] For an account of the leptocephalus stages of *Elops* and *Albula*, see pp. 125 and 136; for the East Indian *Megalops*, see especially Chadabaram and Menon (*18*: 756–759) and Hollister (*42*: 449).

Spawning. Ripe or nearly ripe Tarpon have been captured at Boca Grande, Florida, June 5–22 (*1* [1936]: 41), and several fish containing large roe have been taken from the Panama Canal Zone during February, March, and April (*37*: 25, 30, 35). These observations indicate that at least some of them spawn there during the spring. Captures of both green and spent fish have shown that "the time of spawning on the west coast of Florida is from May to September" (*1* [1936]: 43; *13*: 226).

The general belief that spawning takes place along shore, mostly in shoal water, is borne out by Babcock's report that ripe females as well as males ejecting milt were caught near Boca Grande (*1* [1936]: 41, 43) and that he received an eyewitness account of pairs of Tarpon spawning in Charlotte Harbor, near Fort Myers, Florida. The presence of very young fish at points as widely distributed as Texas, Alabama, Florida, the Bahamas, Puerto Rico, Haiti, Cuba, and Trinidad seems sufficient evidence that the breeding range is extensive—along the shores of both continent and islands from the Gulf of Mexico eastward through the West Indies and Caribbean Sea areas. To what extent it breeds farther southward is not known. The well-known presence of young as well as large Tarpon in Lake Nicaragua also makes it likely that this fish spawns there in fresh water. No evidence, however, has been found that the Tarpon breeds in the lakes of the Panama Canal (*36*: 240). It seems probable, therefore, that the ripe fish there migrates to sea to spawn, using the locks of the Canal as a passageway.

Habits. The Tarpon does not school, at least not habitually like the menhaden, for example. When it does congregate in considerable numbers, as at the foot of the spillways of the dams in the Canal Zone, it does so presumably because food is abundant there. In other places it sometimes congregates in pursuit of schools of fish. The fish apparently is sensitive to cold water and will move away from it if possible. Even in southern Florida it disappears from the inshore waters during cool weather (*34*: 211). If it migrates out to sea, as it probably does at times to escape from cold water, it seems highly probable that it remains at or near the surface where the water generally is warmest and where it can utilize the modified air bladder for breathing. The Tarpon more or less habitually ascends freshwater streams, and in some places, in the tropics at least, it occupies freshwater lakes more or less permanently (*36*: 240; see also *Habitat*).

The rolling movements of the Tarpon at the surface of the water are familiar to all fishermen. As these movements reveal its presence, anglers watch for this activity. Why the fish practices such movements habitually was not understood until it was discovered that it possesses an air bladder supplied with a large amount of lung tissue (*36*: 246). After the fish has rolled at the surface and descended, bubbles appear at the surface, these presumably being air exhaled below the surface.

It has been suggested by several writers that the great leaps often executed by the Tarpon seem to serve a different purpose from rolling movements: to escape from enemies, to shake off remoras or irritating parasites, or to play. Also, it often executes great leaps when hooked, evidently trying to free itself; as most Tarpon fishermen know from experience, these efforts are frequently rewarded with success.

Habitat. The Tarpon, a coastal fish, is seldom if ever seen more than a few miles out from the land. To be sure, it has been credited with extensive seasonal offshore migrations, even across the Gulf of Mexico (p. 118), but not with any definite supporting evidence. The Tarpon may be taken in either salt or brackish water, and not infrequently it lives in freshwater streams and lakes. It has long been known to inhabit Lake Nicaragua, a body of water a hundred feet above sea level, and more recently it has been reported as plentiful in the rapid San Juan River, via which the Lake discharges into the Gulf of Mexico (*1* [1936]: 19–20). This fish is exceedingly abundant, sometimes at least, in fresh or virtually fresh water at the base of the spillway of Gatun Dam and also in Gatun Lake below Madden Dam. It occurs regularly also in other parts of Gatun Lake and in the small freshwater lake between Pedro Miguel and Miraflores locks (*36*: 240). To reach these lakes the fish must pass through the locks of the Canal. The smaller fish also abounds in fresh and slightly brackish streams, as around southwestern Florida. The young fry is often reported as occurring in great numbers in very stagnant brackish pools and lagoons that were not connected to the sea when the collections were made (*22*: 80; *3*: 145; *5*: 34; *12*: 154).

Migrations. Knowledge of this aspect of the Tarpon's life is scanty. It is probable that the great majority of the larval Tarpon passes through the metamorphosis close to the land, and many do so in estuaries, such as the Grande Añasco River, Puerto Rico (*21*: 146), and the Indian River, Florida (*32*: 1). However, some drift so far offshore that they almost certainly are lost to the Tarpon population: one, for example, was taken about 150 miles to the east of Brunswick, Georgia, well out in the Gulf Stream (*27*: 236).

The reported scarcity of fish less than three feet or so off the open coast, contrasted with their abundance in estuarine situations, even in drainage ditches, suggests that most of them tend at first to work inshore. Indeed, great numbers of small fry have repeatedly been encountered in brackish pools in mangrove swamps, in landlocked lagoons, and in small pools around Florida, Puerto Rico, Haiti, Jamaica, and on Andros Island in the Bahamas, access to which is possible only during periods of very high water. Many of the fish that are trapped in this way are no doubt lost to the population when the pools dry up. (For an interesting summary of recorded instances of this sort, see Babcock, *1* [1936]: 24, 32–46.) But many of them probably find their way out again. It is only in situations of this sort that the Tarpon fry has ever been taken in any great numbers, at least around Florida (information from Dr. J. E. Randall). It is to be found in such situations around southwestern and southern Florida throughout the year. The postlarval stages have recently been taken in such numbers in the salt marshes of the Indian River on the eastern coast of Florida as to show that this is an important center of dispersal for them (*32*: 9). Little Tarpon 1–1.5 feet long are very plentiful in the narrow headwaters of brackish and freshwater streams, and even in drainage ditches. But the growing fish tends to move down to the broader waters as it grows.

There is no apparent reason to credit the older Tarpon with any extensive migrations, whether inshore-offshore or along shore, in the southern part of the range, for large fish are found there within rivers and along the open coast at all times of the year.

In the northern part of its range, however, the large Tarpon drops out of sight with the onset of autumn, not to reappear until the following March or later, according to locality. It has often been credited with extensive seasonal migrations, "northward along the Florida coast and down the Texan coast, and back across open waters" (*13*: 234). But a more plausible explanation is that the autumnal disappearance of the Tarpon from the open coasts of the northern-northeastern periphery of the Gulf of Mexico represents nothing more extensive than a temporary withdrawal; it probably moves far enough offshore and deep enough to escape winter chilling, such as killed many of all sizes along the western coast of Florida in 1885, 1894–95, 1905, and 1935 (*74*: 123; *1* [1936]: 21; *66*: 640). Appearance of the Tarpon off North Carolina in summer and autumn (as happens more or less regularly), and even farther north (p. 120), evidently represents so extensive a journey from the nearest wintering ground available for a warm-water nonoceanic fish that it seems unlikely that any of those ever find the way back to their southern home.—H.B.B.

Food. The Tarpon, so far as known, is wholly carnivorous. A specimen nearly six feet long from Boca Grande, Florida, examined by me, had the remains of six marine catfish in its stomach; and a 12-inch specimen from the same place had ingested a silverside. The Tarpon has been reported as feeding almost exclusively on cutlassfish, e.g. in Calcasieu Pass, Louisiana (*73*: 170–172). At times it gathers in great abundance at the foot of the spillway of Gatun Dam in the Canal Zone and at the spillway of Madden Dam in the upper part of Gatun Lake, presumably for the purpose of feeding on small fish that are carried over the spillways. Various observers have reported that it will follow schools of mullets, anchovies, and other fish, apparently feeding on them at will. Young Tarpon, ranging from about two to eight inches in length, taken in an isolated lagoon at Port-au-Prince, Haiti, had fed exclusively on "aquatic hemiptera which filled the waters of the lagoon" (*5*: 36). Blue crabs constitute a favorite bait in Florida.

Enemies. The chief natural enemy of the large Tarpon is undoubtedly the shark, and it has been reported that the porpoise attacks it too (*1* [1936]: 64); the small Tarpon quite certainly falls prey to many predators in the sea. The Tarpon's chief protection from enemies is apparently its great swimming speed, whereby it escapes.

Variation. Whether geographical variations exist can be determined only from study of a larger number of specimens, collected from many localities, than have been available to me.

Relation to Man. As a gamefish, the Tarpon scarcely is surpassed. Its reputation is world-wide and much has been written about the requirements for capturing and subduing this powerful, hard-fighting fish. Its great strength became evident to the writer one day when he was helping to land a Tarpon 80 inches long. A man standing nearby saw the great fish leap ashore from the seine, and wishing to prevent it from jumping back into the water, he threw himself on it, evidently believing that he had enough strength and weight to manage the fish. However, with one stroke of the tail the fish lifted the man, who weighed at least 150 pounds, and threw him a distance of about 12–15 feet. It is understandable, then, why considerable strength, skill, patience, and determination are required to land a large Tarpon and why Tarpon fishing is exciting.

About angling for Tarpon, Miss Francesca LaMonte has provided the following information (personal communication). The hard-fighting Tarpon, either large or small, is a prized catch wherever it occurs in western Atlantic waters, from Nova Scotia to Argentina, or in the eastern South Atlantic off Lagos, Nigeria, and at the mouth of the Volta River, Ghana. The most famous western North Atlantic grounds for both numbers of fish and facilities are: the Florida Keys, centering around Islamorada and Marathon; the western coast of Florida, especially in the passes near Boca Grande and Useppa Island; the Rio Pánuco, México; and the Rio Encantado, Cuba.

The number of Tarpon caught is always small in comparison with the number present, for the fish puts up a violent and often successful fight. A large one is usually fished from outboard motor boats (with the motor cut) by casting, trolling, drifting, or still fishing, on 12-pound line or less, with plugs or with either live or dead bait, and with or without a drag on the reel. The first problem is to set the hook in the Tarpon's hard mouth, then to prevent the fish from throwing it or breaking the line, both of which it will try to do. First it will make a fast, powerful run and a series of high, twisting leaps, shaking its head with violence. Failing to throw the hook, it will then try to break the line either by charging at the boat if the line is too tight, or, if too loose, taking off into the mangroves where the line will eventually break on the roots. The small young Tarpon is caught in rivers and canals on fly-fishing or spinning tackle with light monofilament line. Though small, it fights just as hard as the adult and is by no means sport for an inexperienced angler.

There is wide diversity of opinion as to the edible qualities of Tarpon flesh. On our own shores "large ones at least are not edible" (Babcock, *1* [1936]: 63), but in Panama it is highly esteemed by the natives and West Indian immigrants (*36*: 239); there the size of the fish receives no consideration, for an 80-inch Tarpon seemed as acceptable as a small one; as stated by me in the paper just cited, a small fishery for Tarpon was in operation in Gatun Lake in 1935. It has been reported that it is highly prized as food by the Indians of the Caladonia Bay (Panama) region (*10*: 152). In the United States the commercial value of the Tarpon is so slight that it has not been listed in the statistical reports of the commercial fisheries by the former Bureau of Fisheries or by the present U.S. Fish and Wildlife Service.

Range and Abundance. The regular range of the Tarpon extends from North Carolina to central Brazil, and it is probable that the Tarpon frequents the Brazilian coast southward to Pernambuco, or even to Bahia,[5] though the most southerly definite record is for Lake Papary, Rio Grande do Norte, in the general vicinity of Natal (*65*: 8). Thence northward the range is evidently unbroken around the South American coast, where it has been recorded for: Marajó Island at the mouth of the Amazon (*8*: 298); French Guiana (*57*: 164); Trinidad, where it has been reported as very plentiful (*69*: 26); and Lake Maracaibo, Venezuela, and its tributary Rio Concha, where several were seen rolling and a school was reported (*62*: 33). It is equally omnipresent in suitable situations all along the Central American littoral, including: the Panama Canal to Gatun Lake; the San Juan River (p. 117); and Lake Nicaragua, where it is so plentiful that a recent writer reported seeing "more than a dozen rolling at the surface at one time" (*52*: 184). As every angler knows, the Tarpon abounds near river mouths and in so-called "passes" along the coasts of México and Texas. Indeed, it is not unusual to find a Tarpon 80 or 100 miles up from the sea in some Mexican rivers (*13*: 219). In fact, the Bay of Campeche, just west of Yucatán, was the site of a more or less regular fishery for it as early as about 1675 (Capt. Wm. Dampier, cited from Gowanloch, *29*: 145–146). Proverbial centers of abundance are the mouth of the Pánuco River, near Tampico, México, and Aransas Pass, Texas. The Tarpon, as Gowanloch (*29*: 154) expressed it, is to be found near almost any coastal island or bay of Louisiana, Alabama, the western coast of Florida, and the eastern coast of Florida, northward in summer about to the vicinity of Daytona. Especially renowned fishing grounds are: the Calcasieu River, some 30 miles east of the Texas boundary; Grand Isle, Louisiana; Boca Grande and Captiva, western Florida; the waterways and rivers among the Thousand Islands, and the interior waterways of the Florida Keys (see also p. 119).

The Tarpon is widespread but seemingly not very abundant except perhaps locally throughout the West Indian region in general. More than a century ago it had been reported in scientific literature for Guadeloupe, Martinique, Santo Domingo, and Jamaica (*20*: 399). It has been reported for Haiti (*3*: 143) and is common around the Barbados and Puerto Rico. In some rivers of Cuba it is so abundant that a party of anglers has reported hooking 105 large ones in a day in the Rio Encantado (*33*: 205). Among the Bahamas a few are seen, and an occasional one is taken off Bimini (*33*: 207; also personal communication from Vladimir Walters); it is common around Andros Island (*11*: 66), and is taken or seen occasionally around Bermuda.

The Tarpon ranges in small numbers northward to North Carolina in some summers, and perhaps every summer; but large schools are sometimes seen as far north as Cape Lookout. A five-foot fish has been taken off Hatteras, and the North Carolina State Museum has one of 119 pounds from Beaufort, and another of 176 pounds from Wilmington (*64*: 115). But it appears only as a straggler and at irregular intervals farther north. It has been reported for the lower part of Chesapeake Bay by fishermen (*38*: 80); there are odd records of it for New Jersey, near Sandy Hook (*23*:

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[5] The first published account of the Tarpon, by Marcgrave (*50*), was probably based on examples from Recife (Pernambuco) or Salvador (Bahia).—G. S. Myers.

264), for the eastern end of Long Island, New York (*55*: 33), and for Rhode Island (*68*: 72). The Tarpon has been reported as being taken in small numbers almost every year in the vicinity of Woods Hole, Massachusetts (*67*: 741). But the Tarpon has been reported only once for the Gulf of Maine, when a specimen was taken at Provincetown at the tip of Cape Cod on July 25, 1915 (*6*: 91). Northward from Cape Cod there are only five records of it, all for Nova Scotia—one from Isaac Harbor (*31*: 45), one from Harrigan Cove (*70*: 53), one of about three feet caught near Terrence Bay, September 6, 1947, and two taken near Halifax on August 3–4, 1953 (information from Dr. A. H. Leim). The Tarpon is common on the coast of tropical West Africa (*25*: 154; *43*: 106; *1* [1951]: 18–19).

Synonyms and References:[6]

Clupea gigantea Shaw (in part), Genl. Zool., *5* (1), 1804: 173 (no type or type local. design., diagn., genl. acct., habitat).[7]

Megalops giganteus Voigt *in* Cuvier, Das Thierreich (German transl.), *2*, 1832: 423 (refs.; cf. Amer. *M. giganteus* and east. *M. filamentosus* Lacépède); "Disciples' edition" of Cuvier's Règne Anim., *1*, 1836: 559 (same as above with somewhat more extended descr.); Eng. ed., *10*, 1834: 442 (design. Amer. species as *M. cyprinoides*, with ref. to Bloch's pl. 403; pelvics under anterior part of dorsal are as in *Megalops cyprinoides* Broussenet as now understood, but 15 rays in dorsal suggest *Tarpon*).

Megalops atlanticus Cuvier and Valenciennes, Hist. Nat. Poiss., *19*, 1846: 398 (orig. descr., type local. Guadeloupe, Santo Domingo, Martinique, Puerto Rico; types in Paris); Poey, Repert. Fisico-Nat. Cuba, *2*, 1868: 423 (diagn., brackish water of Cuban rivers, attains 5 feet); An. Soc. esp. Hist. Nat., *4*, 1875: 146 (Cuba, Jamaica, Puerto Rico, Santo Domingo, Martinique, Trinidad, México, British Guiana); *in* Gundlach, An. Soc. esp. Hist. Nat., *10*, 1881: 343 (Puerto Rico, Cuba, Santo Domingo, Martinique, México); Henshall, Bull. U.S. Fish Comm. (1889), *9*, 1891: 385 (effect of cold water); Boulenger, Ann. Mag. nat. Hist., (6) *20*, 1897: 298 (Marajó I., Brazil); Gill, Smithson. misc. Coll., *48*, 1905: 35 (descr., habitat, game qualities, life hist., common names, etc.); Regan, Ann. Mag. nat. Hist., (8) *5*, 1910: 354 (caudal skel. cf. *M. cyprinoides*); Fowler, Proc. biol. Soc. Wash., *33*, 1920: 147 (Cape May, Monmouth and Ocean counties, New Jersey); Proc. Acad. nat. Sci. Philad., *80*, 1929: 609 (Barnegat Inlet, Atlantic Highlands, and Atlantic City, New Jersey); Copeia, 1931: 46 (sport fish, Port Aransas and Point Isabel, Texas); Bull. Amer. Mus. nat. Hist., *70* (1), 1936: 154, fig. 61 (African recs.; descr. based on Amer. specimens); Puyo, Bull. Soc. Hist. nat. Toulouse, *70*, 1936: 65, 163 (diagn., habitat in French Guiana); Cadenat, Rev. Trav. Off. Pêches marit., *10*, Fasc. 4, Liv. 4, Pt. 2, 1937: 441, figs. 5, 6 (refs., remarks); Norman and Fraser, Giant Fishes, 1938: 93, fig. 34 (semipopular acct.); Puyo, Faune Emp. Franç., 12, Poiss. Guijane Franç., 1949: 151, fig. 75 (descr., Fr. Guiana).

Megalops elongatus Girard, Proc. Acad. nat. Sci. Philad. (1858), 1859: 224 (orig. descr., type local. Long Island, New York; type not preserved).

Megalops thrissoides Günther (not of Bloch and Schneider, which probably is *M. cyprinoides*), Cat. Fish. Brit. Mus., *7*, 1868: 472 (diagn., Jamaica, Cuba, Trinidad, Brit. Guiana); Goode, Bull. U.S. nat. Mus., *5*, 1876: 68 (rare in Bermuda); Yarrow, Proc. Acad. nat. Sci. Philad., 1877: 215 (Ft. Macon, North Carolina); Steindachner, Denkschr. Akad. Wiss. Wien, *39*, 1878: 69 (Magdalena R., Colombia); Jordan

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6. The Tarpon has been discussed in so many popular books and periodicals that it does not seem practical to list all references to them. Therefore, only some popular accounts are cited, and only those citations in scientific periodicals that seem to contain substantial information. African records have been omitted except for references to Fowler (*25*) and Cadenat (*14*), whose publications contain important references to African literature treating the species.
7. This name was based by Shaw upon Marcgrave (*50*), who dealt entirely with the Atlantic Tarpon, and upon *Clupea cyprinoides* of Bloch, which is a composite of the Tarpon and the Pacific *Megalops cyprinoides* (Broussonet). Since Shaw's account is thus a composite, it devolved upon a subsequent revisor to assign the name *gigantea* to one of the included species. This was done by Cuvier (*19*: 324), who definitely assigned the name *gigantea* to the American Atlantic species. It would thus appear that the correct name of the Tarpon should be *Tarpon giganteus* (Shaw), but the name *atlanticus* is so well established that its conservation, under suspension of the International Rules, would seem to be worthwhile.—G. S. Myers.

and Gilbert, Bull. U.S. nat. Mus., *16*, 1883: 262 (descr., distrib.); Willcox, Bull. U.S. Fish Comm. (1886), *6*, 1887: 123 (effects of cold); Henshall, Bull. U.S. Fish Comm. (1894), *14*, 1895: 211 (abund. in Florida; food and game qualities; size; etc.).

Megalops — Gill and Bransford, Proc. Acad. nat. Sci. Philad., *29*, 1877: 187 (Toro Rapids, below Lake Nicaragua; eaten by natives).

Tarpon atlanticus Jordan and Evermann, Bull. U.S. nat. Mus., 47 (*1*), 1896: 409 (descr., range, synon.); 47 (*4*), 1900: fig. 177; Smith, Bull. U.S. Fish Comm. (1897), *17*, 1898: 90 (Woods Hole, Massachusetts); Evermann and Kendall, Rep. U.S. Comm. Fish. (1899), 1900: 54 (Florida); Linton, Bull. U.S. Fish Comm. (1899), *19*, 1901: 437 (parasites); Evermann and Marsh, Bull. U.S. Fish Comm. (1900), *20* (1), 1902: 80, fig. 10 (descr., small specimens from Puerto Rico); Gregg, Where to Catch Fish. E. Cst. Fla., 1902: 31, fig. (descr., fishing instruct., nonedible or barely so); Eigenmann, Bull. U.S. Fish Comm. (1902), *22*, 1903: 222 (20–192 mm specimens, no descr., Pinar del Rio, Cuba); Bean, Bull. N.Y. St. Mus., *60*, Zool. 9, 1903: 177 (synon., descr., New York); Hargraves, Fish. Brit. Guiana, 1904: 4 (local name Cuffum; used but not appreciated as food; fresh and brackish water); Smith, N.C. geol. econ. Surv., *2*, 1907: 114, fig. 36 (synon., descr., feed., range, North Carolina); Meek, Field Mus. Publ., Zool., *7*, 1907: 99, 111 (Lake Nicaragua); Fowler, Proc. Acad. nat. Sci. Philad. (1910), *62*, 1911: 599 (New Jersey); Eigenmann, Mem. Carneg. Mus., *5*, 1912: 444 (Georgetown, Brit. Guiana); Sumner, Osburn, and Cole, Bull. U.S. Bur. Fish. (1911), *31* (2), 1913: 741 (Woods Hole, Massachusetts); Cockerell, Bull. U.S. Bur. Fish. (1912), *32*, 1913: 122 (scales descr.); Gudger, Proc. biol. Soc. Wash., *26*, 1913: 104 (North Carolina); Halkett, Check List Fish. Canada, 1913: 45 (Isaac's Harbor, Nova Scotia); Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 8 (Lake Papary, Rio Grande do Norte, Brazil); Fowler, Proc. Acad. nat. Sci. Philad., *67*, 1915: 245 (various Florida locals.; color relative to habitat; cleaning of "spawning beds"); also 522 (Trinidad, B.W.I.); Coker, Copeia, 1921: 25 (small ones Dauphin I., Alabama); Eigenmann, Mem. Carneg. Mus., *9*, 1922: 179 (fresh water, Magdalena R. Colombia); Meek and Hildebrand, Field Mus. Publ. Zool., *15* (1), 1923: 174 (synon., descr., range Panama); Schroeder, Rep. U.S. Comm. Fish. (1923), Append. 12, 1924: 4 (commerc. val., Key West Florida); Bigelow and Welsh, Bull. U.S. Bur. Fish. (1924), *40* (1), 1925: 91, fig. 38 (descr., range, rare in Gulf of Maine); Breder, Zoologica, N.Y., *4* (4), 1925: 140, 152 (numerous at spillway, Gatun Dam, C. Z.; enters Caladonia Bay, Panama, in schools; highly prized as food by local Indians); Nichols and Breder, Zoologica, N.Y. (1926), *9* (1), 1927: 33, fig. (distr., life hist., size); Beebe, Bull. N.Y. zool Soc., *30* (5), 1927: 141 (young adults from brackish lagoon, Haiti); Hildebrand and Schroeder, Bull U.S. Bur. Fish. (1927), *43* (1), 1928: 80, fig. 41 (synon., descr., range, Chesapeake Bay); Beebe and Tee-Van, Zoologica, N.Y., *10* (1), 1928: 33, fig. (descr., Port-au-Prince, Haiti); Whiton and Townsend Bull. N.Y. zool. Soc., *31*, 1928: 170 (feed., food in Calcasieu R., Cameron Parish, Louisiana): Breder Field Bk. Mar. Fish. Atl. Cst., 1929: 59, fig. (diagn., distr., habits, food value, size); Jordan, Manua Vert. Anim. NE U.S., ed. 13, 1929: 37 (diagn., range, size); Nichols, N.Y. Acad. Sci., *10* (2), 1929 198, fig. (range, Puerto Rico; diagn., habits); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish (1928), *2*, 1930: 29 (common names, range, synon.); Burr, Bull. Texas Fish Game Comm., No. 5 1932: 36 (numbers at Port Aransas and Point Isabel, Texas); Beebe and Tee-Van, Field Bk. Shore Fish Bermuda, 1933: 33, fig. (descr., uncommon in Bermuda); Breder, Bull. N.Y. zool. Soc., *34*, 1933 65–67 (small ones from pond, Andros I., Bahamas; food); Gregory, Trans. Amer. philos. Soc., *2* (2), 1933: 137–142, figs. 31–34 (skull descr., cf. *Elops* and prehist. relatives); Storey and Perry Science, *73* (2022), 1933: 284 (young adults, Sanibel I., Florida, and elsewhere); Gowanloch Bull. La. Conserv. Dep., *21*, 1932: 8, 54–65 (genl. acct.); Bull. La. Conserv. Dep., *23*, 1933: 144–168 (account of 1932 enlarged); Breder, Zoologica, N.Y., *18*, 1934: 58, 59 (fresh water, Andro I., Bahamas); Hildebrand, Copeia, No. 1, 1934: 45 (larval Tarpon descr.); Beebe and Hollister, Zoologica, N.Y., *19* (6), 1935: 211 (from Union I., Grenadines, B.W.I.); Vladykov and McKenzie, Proc N.S. Inst. Sci., *19* (1), 1935: 53, fig. 26 (two Nova Scotian recs.); Babcock, The Tarpon, ed. 4 1936: 1–175, illustrated (good genl. acct. and much scientific data on anat., habitats, breed., respir. etc.); Hollister, Zoologica, N.Y., *21* (4), 1936: 263 (caudal skel.); and *24* (4), 1939: 449–47 (caudal skel. and other characters cf. *Megalops cyprinoides*); Miller, Forest and Stream, *41* (1), 1936 32–33 (fishery in Rio Frio, tributary of L. Nicaragua); Gudger, Amer. Mus. Novit., 944, 1937: 1 fig. 2 (albino descr.); Heilner, Salt Water Fishing, 1937: 195–210 (genl. acct.; abund. in Cub and elsewhere); Hildebrand, Sci. Month., *44*, 1937: 239–248, 4 figs. (Panama Canal; locally prized a food by natives); Kaplan, Big Game Angler's Paradise, 1937: 89–136 (genl. acct.); Storey, Ecology, *18*, 1937: 12 (always hurt by freezes); Breder, Bull. N.Y. zool. Soc., *41*, 1938: 24 (irreg. in New York Harbor); *42*, 1939: 154–155 (habitat of small ones at Sanibel I., Florida); Butsch, J. Barbados Mus. hist. Soc., *7* (1), 1939: 18 (common locally); Heilner, Bk. of Fishes, Nat. Geogr. Soc., 1939: 202, 327–336 (color plate, genl. acct.); Hildebrand, Zoologica, N.Y., *24* (1), 1939: 19, 25, 30, 35 (in locks of Panama Canal; transit through Canal completed); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 5 (feed.; descr., especially as seen by a diver; Tortugas, Florida); Breder, Zoologica, N.Y., *27* (1), 1942: 1 (behavior and respir. in confinement, refs. to papers on same subject); Breder, Zoologica, N.Y., *29*, 1944: 217–252 (habitat, body proportions, growth, movements, refs.).

Genus *Elops* Linnaeus 1766

Ladyfish

Elops Linnaeus, Syst. Nat., ed. 12, 1766: 518; type and only included species, *Elops saurus* Linnaeus 1766.

Generic synonyms:

Argentina, in part, Linnaeus, Syst. Nat., ed. 12, 1766: 519, for *A. carolina* Linnaeus.

Mugilomorus Lacépède, Hist. Nat. Poiss., 5, 1803: 398; type and only included species, *Mugilomorus anna-carolina* Lacépède equals *Elops saurus* Linnaeus.

Trachonotus Rafinesque, Anal. Nat. . . ., 1815: 88; type species *Mugilomorus anna-carolina* Lacépède; *Trachonotus* proposed as a substitute for *Mugilomorus* Lacépède.

Characters.[8] BODY slender. VERTEBRAE about 75. PSEUDOBRANCHIAE large. BRANCHIOSTEGALS about 34. MOUTH nearly horizontal and almost terminal. LATERAL LINE straight, with simple tubes. SCALES small, not especially primitive (fully described by Cockerell, *15*: 3; *17*: 122), forming a sheath on base of dorsal and anal fins. DORSAL rather high anteriorly, the last ray not prolonged. ANAL similar to dorsal but smaller, placed far behind dorsal. PELVICS inserted near vertical from origin of dorsal. Last several segments of spinal column directed upward toward base of upper lobe of caudal fin.

AIR BLADDER slender, with very transparent walls, occupying full length of abdominal cavity, adhering to abdominal wall dorsally and to alimentary canal ventrally. ALIMENTARY CANAL, below air bladder, consisting of a straight tube except for a large elongated blind sac that projects forward to throat below, and parallel to, the main canal; a mass of coeca (firmly bound together) attached to distal end of blind sac and forming a close-fitting shield on right side of sac throughout its length; one lobe of liver forming a hood over blind end of sac, and another lobe shielding left side of sac.

Remarks. The gular plate distinguishes this genus from *Albula*. The very slender body, the small scales, and the absence of filaments attached to the last ray of the dorsal and anal fins distinguish it from *Tarpon*.

Range. About seven species have been recognized, but only *Elops saurus* comes within the range of this work. The species are widely distributed in the warmer seas, entering estuaries and tidal streams.

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[8] The characters of the skull have been discussed by Gregory (*30*: 138), who regarded it as rather more primitive than that of the tarpon. The ganoid character of the caudal skeleton has been well described and correctly figured by Hollister (*39*: 260–263).

Elops saurus Linnaeus 1766

Ladyfish,[9] Bigeye Herring, Tenpounder, Skipjack, Macabi, Matejuelo Blanco, Matejuelo Real, Long John, Benane

Figures 20, 21

Study Material. Many specimens, including an almost complete growth series ranging from larvae to adults 550 mm long.

Distinctive Characters. See *Remarks*, p. 123.

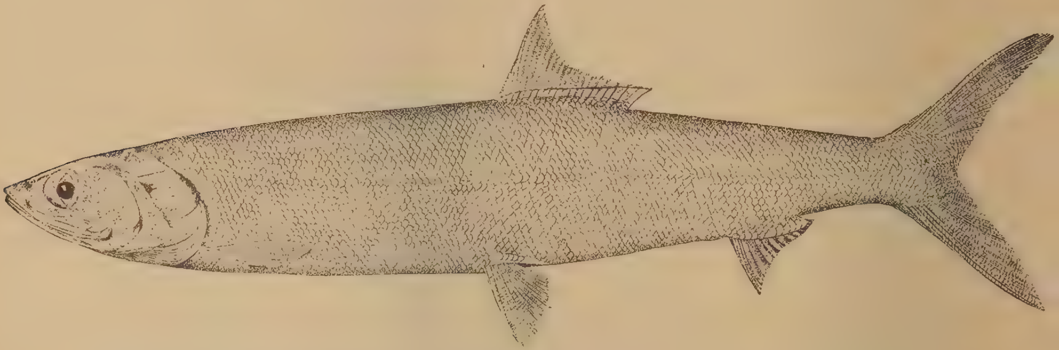

FIGURE 20. *Elops saurus*; U. S. National Museum specimen. Drawn by H. L. Todd.

Description. Proportional dimensions in per cent of standard length, based on study specimens.

Body: depth 14.5–19.3.
Head: length 25–31.
Snout: length 5.8–7.0.
Eye: diameter 5.0–6.3.
Maxillary: length 14.5–17.8.
Anal fin: length of base 9.8–11.8.
Pectoral fin: length 14–16.

Scales: 103–120.
Branchiostegals: 26–32.
Gill rakers: 6–8+10–15 (excluding rudiments).
Fin rays: dorsal 21–25; anal 14–17; pectoral 16 or 17.
Vertebrae: 73–80 (10 specimens).

BODY very slender, only moderately compressed, its depth 5.2–6.9 in SL. SCALES small, thin, with crenulate membranous border (fully described by Merriman, *51*: 113). LATERAL LINE nearly straight, extending onto base of caudal. HEAD low, flat above, 3.25–4.0 in SL. SNOUT rather long, usually a little longer than eye, 4.1–4.75 in head. EYE near upper profile, wholly in anterior half of head, 4.55–5.2 in head. INTERORBITAL flat, 5.7–8.4 in head. GILL RAKERS about 67% of the eye, scarcely denticulate, their entire surface rough, generally 1 or 2 rudiments in large specimens and 2 or 3 in small ones, on upper and lower limbs of first arch; the lower counts given, for this reason, are invariably based on the smaller specimens. MOUTH nearly horizontal, almost terminal, the lower jaw slightly included. MAXILLARY reaching somewhere under posterior half of eye in young adults, far beyond eye in large examples, 1.7–2.0 in head.

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[9] In scientific literature, as well as in earlier popular books on American game fishes, the name Ladyfish was usually applied to *Albula vulpes* (p. 134). But to the angler, who alone takes much interest in either of them, "Ladyfish" means *Elops* while *Albula* is universally termed "Bonefish."

DORSAL fin rather high anteriorly, its longest rays usually reaching tip of last ray if deflexed, its outer margin rather deeply concave, its origin about equidistant between base of caudal and anterior margin of eye. CAUDAL very deeply forked, the upper lobe rather longer than the lower one, usually about as long as head. ANAL moderately small, far behind dorsal, its origin usually about equidistant between base of caudal and base of pelvic, its base 2.4–2.9 in head. PELVIC fin not much smaller than pectoral, inserted under, or slightly in advance of, origin of dorsal, scarcely nearer to origin of anal than to base of pectoral. PECTORAL fin rather broad, not falcate, reaching scarcely halfway to pelvic in large examples, somewhat more than halfway in small ones, 1.75–2.0 in head. AXILLARY SCALE of pectoral extending to about the midlength of fin, 3.0–3.9 in head.

Color. Preserved specimens uniform bluish gray above, silvery elsewhere; dorsal and caudal more or less dusky; other fins pale.

A large fresh specimen bluish on back, with sides silvery; slightly yellowish below. Dorsal and caudal dusky and yellowish; pelvics and pectorals yellowish with dusky punctulations (*38*: 78).

Size. Although a maximum of 900 mm (36 in.) TL has been reported (*45*: 410), the usual length probably is under 500 mm (20 in.). The largest individual seen by me was 730 mm (610 mm SL; 29.2 in.); this large fish occurred among hundreds of adults stranded in the Gatun Locks of the Panama Canal in 1935 when the Locks were drained. In my file is a record of another large one, 718 mm (28.75 in.), caught at Punta Gorda, Florida. Although one of the common names is Tenpounder, weight records indicate that this fish probably never weighs that much. A specimen 470 mm long (18.8 in.) weighed a pound, another of 550 mm (22 in.) weighed 1.6 pounds, and still another 625 mm (25 in.) weighed 2.7 pounds; 82 fish, ranging between 400–600 mm (16–24 in.), with an average length of about 450 mm (18 in.), weighed 100 pounds.

Development. The eggs and the earliest stages of the leptocephalus are unknown. Of the many leptocephalus larvae studied, the youngest ones, judging principally by the development of the fins, are 34, 35, and 37 mm long. Although the forked caudal is well developed, the other fins are virtually undifferentiated; the alimentary canal is very loosely attached to the abdomen, as in larval herrings and anchovies, and the vent is less than a head-length from the caudal base.

Two leptocephali, 34.5 and 36.5 mm long, are slightly more advanced; in these a thickening within the finfold where the bases of the dorsal and anal are developing has taken place, though rays are not yet definitely formed. The head is strongly depressed, the mouth is terminal and large, and the snout, viewed ventrally, is rather sharply triangular; these characters at once distinguish the leptocephalus of this species from that of *Albula vulpes*. The myomeres are mostly quite distinct, 78 having been counted in one of the specimens. A row of faint dark spots, which are much more distinct in older leptocephali, is present on each side just above the alimentary canal.

Three leptocephali, 42, 42, and 44 mm long, are the longest larvae in the collections studied and may represent about the maximum length attained in the leptocephalus stage. Here development has progressed somewhat beyond that of the specimens described above, for the rays are evident now in the dorsal and anal fins, though an accurate enumeration cannot be made. The anal fin is removed from the base of the caudal by a distance shorter than the head, and the primitive membrane has remained between the two fins. The pectoral fins are represented by tufts of membrane and the pelvics merely by thickened places in the abdominal wall where their bases are developing. Seventy-seven myomeres were counted in one of the specimens.

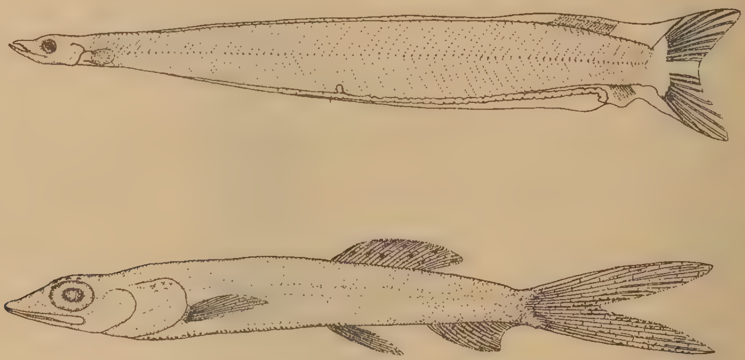

FIGURE 21. *Elops saurus*. ABOVE, leptocephalus, 35 mm long; BELOW, young fish, 20 mm TL, recently transformed.

In a considerably older specimen, reduced in length to 27 mm, the body, though still quite flat, has become much more substantial than in the younger stages described. The dorsal and anal fins are sufficiently developed to permit an accurate enumeration of the rays, and the anal fin is now well separated from the caudal. The primitive membrane has disappeared behind the fin, though a short section of it remains in front. The pectorals are rather well developed and show signs of rays. However, the pelvics are undifferentiated.

A virtually young adult only about 16 mm long (not in good condition) represents the maximum "shrinkage" in length during metamorphosis, among specimens studied. Though the body has become rather robust, the head and especially the snout remain depressed. The fins, except for the pelvics, are rather well developed. The intestinal canal remains loosely attached to the abdomen as in younger fish, and the primitive rows of dark dots on each side of the canal are distinct.

The state of development varies widely among the rather numerous young adults, 18 mm and upward. For example, a specimen scarcely 20 mm long is fully as well developed as others around 30 mm, and another specimen about 30 mm long is just as well developed as some between 35 and 40 mm. The small and exceptionally well developed specimens have advanced especially far in color. A specimen scarcely 20 mm long already has some of the silvery color of large adults and all the juvenile markings are missing, whereas a 32-mm specimen among the retarded ones is very pale and still retains the two rows of dark spots on the abdomen, as in the leptocephali. Even in the most retarded specimens, the fins are all well developed at a length of 22 mm, and the outline of the gular plate is visible under magnification. Scales begin to appear in at least some specimens at a length of 50 mm, and the teeth in the jaws are definitely in narrow bands. At a length of 60–65 mm, scalation generally is complete, and the fish are very similar to full-grown adults.

The environment probably affects the development profoundly, for the small, exceptionally advanced specimens described in the preceding paragraph were taken in brackish pools at Key West, Florida, whereas the notably larger and more retarded ones were taken at sea off Ocracoke and Beaufort inlets, North Carolina.

Spawning. There is relatively little information about the actual time and place of spawning. However, in 1939 I reported (*37*: 25) that 20 individuals, selected at random from among the many left stranded when the Gatun Locks (Panama Canal) were drained in February 1935, consisted of seven ripe or nearly ripe males (56.5–62 cm TL), and 13 females (63.5–73 cm TL) with large roe, indicating that spawning time in that vicinity was at hand. Although leptocephali of *Albula* have been taken in considerable seining during the winter and spring months on the Atlantic coast of Panama, no young of *E. saurus* have been reported. On the Pacific coast of Panama, leptocephali of the closely related *E. affinis* were taken during February, August, and "autumn." In the collections at hand there are leptocephali from Texas, mostly from the vicinity of Corpus Christi, collected in February, March, April, and November. Young adults were taken in Aransas Pass, Texas, during June, and at Key West, Florida, in March and November. Leptocephali are also at hand from the Florida Keys, taken in November, and from Cuba, caught during May. For Beaufort, North Carolina, there is a note in my files that a nearly ripe female of 604 mm was taken on October 3, 1912; leptocephali were collected there during January, February, March, April, May, October, November, and December; rather recently-transformed young adults were taken in the same vicinity during March, May, June, July, and August. Most of the many leptocephali studied were taken with tow nets on the bottom, at sea, in comparatively shallow water, though several captures were made in estuaries. The young adults, except for a few lots in the transition stage, were collected with seines in inside waters, partly in brackish ponds and pools.

Habitat. This is an active little fish, often traveling in schools, frequently skipping at the surface, and jumping when hooked. Its usual habitat is shallow salt and brackish water. The young adult has been taken in brackish lagoons and in ponds and pools, perhaps more or less recently and temporarily separated from the sea. In the Gatun Locks (see above) it occurred in large numbers and was most numerous in the middle chamber of the three flights, where the water, at least part of the time, is nearly fresh. No evidence of its entrance into the strictly fresh water of Gatun Lake was obtained; it seems improbable, therefore, that it uses the locks as a passageway; more probably the locks serve merely as a feeding ground. If it migrates to sea to spawn, as might be supposed since its young pass through a leptocephalus stage, the location of its spawning ground (or grounds) remains unknown.

Food. Its diet has not been thoroughly studied, but the short alimentary canal and the well-armored mouth surely suggest a flesh diet. A dozen or so adults taken in one catch at Beaufort, North Carolina, had fed exclusively on shrimp, and other examples from the same vicinity had fed on them also (*48*: 352; *64*: 116). It has been reported that an individual from Haiti had eaten a shrimp and two small fish of its own species (*5*: 33). A specimen taken in Connecticut had fed on two small fish, probably *Menidia* (*51*: 113). According to Kaplan, the Ladyfish feeds on shrimp, shiners, and squid (*46*: 91).

Parasites. The cestode parasite, *Rhynchobothrium bulbifer* Linton, has been found in the viscera of the adult Ladyfish (*48*: 352).

Relationships. This species is closely related to *E. affinis* Regan of the Pacific coast of tropical America, apparently differing only in the number of gill rakers: in 41 specimens of *E. saurus* examined, 9 had 6 rakers, 16 had 7, and 16 had 8, exclusive of rudiments, on the upper limb of the first arch; and in 88 specimens, 2 had 10 rakers, 7 had 11, 13 had 12, 28 had 13, 35 had 14, and 3 had 15 rakers, exclusive of rudiments, on the lower limb. In nine specimens of *E. affinis* examined, 4 had 10 and 5 had 11 rakers on the upper limb, and in 26 specimens, 2 had 16 rakers, 4 had 17, 6 had 18, 11 had 19, and 3 had 20 rakers, exclusive of rudiments, on the lower limb.

Elops saurus has been recorded for West Africa by Fowler (*25*: 155) and by others, but Regan (*58*: 38) has held that African specimens were distinct on the basis of fewer vertebrae—68 or 69 compared to 78 or 79 for American specimens—and on the basis of fewer scales—94–98 for African specimens and 102–118 for American specimens. According to counts made by me, these differences seem to be constant. Ten American specimens have 73, 74, 75, 75, 75, 77, 78, 79, 80, and 80 vertebrae, and nine American leptocephali have 77, 78, 78, 78, 79, 80, 82, 82, and 82 myomeres, whereas one adult from Ashantee, Africa, has only 67 vertebrae. Counts of scales in 22 American specimens resulted as follows: 1 specimen with 103, 2 with 105, 1 with 106, 2 with 107, 2 with 108, 1 with 109, 2 with 110, 1 with 111, 2 with 112, 1 with 113, 1 with 114, 1 with 115, 2 with 116, 1 with 118, and 2 with 120. The three specimens from Ashantee, Africa, examined by me have 92, 97, and 100 scales. Although the range of counts for American specimens is rather great, it does not overlap that given by Regan for African specimens. On the basis of the above data given by Regan and me, the African representatives, which Regan named *Elops senegalensis*, may still be considered distinct, though synonomized with *E. saurus* by Fowler.

Variations. No geographical variation in the number of gill rakers has been discovered, but there appears to be a slight increase in number with age, which seemingly may be attributed to the development of some of the rudiments into rakers as the fish grows. Thus, in 29 specimens 150 mm SL and under, 5 had 5, 14 had 6, and 10 had 7 rakers and 2 or 3 rudiments on the upper limb; among 20 specimens over 150 mm SL, 2 had 6, 4 had 7, and 14 had 8 rakers and 1 or 2 rudiments. Similarly, among 35 specimens 150 mm SL and under, 5 had 10, 14 had 11, 11 had 12, and 5 had 13 rakers and 2 or 3 rudiments on the lower limb; among 32 specimens over 150 mm, 4 had 12, 7 had 13, 18 had 14, and 3 had 15 rakers and 1 or 2 rudiments on the lower limb.

Relation to Man. For its size, the Ladyfish affords good sport to the light-tackle angler, but it is virtually of no value as food, its meat being dry and bony. It is seen from time to time in the market at Colón, Panama, where it is known as "bonyfish" to the West Indian Negro immigrants who speak English; however, the demand for it is small. When the Gatun Locks were drained in 1935, hundreds of Ladyfish became stranded, and it was estimated that more than 1,000 pounds perished. While the employees and the native residents eagerly accepted tarpon, crevalle jack (*Caranx hippos*), and other species, the Ladyfish was entirely neglected and had to be buried (*37*: 25).

Range and Abundance. Its range extends from Cape Cod to Brazil. The southernmost locality for which it has been recorded seems to be Rio de Janeiro (*60*: 90; *26*: 132). While *E. saurus* is not numerous in the West Indies, it is widespread in the Caribbean-Gulf of Mexico region, and is common along Atlantic Panama; the *Study Material* includes three specimens from the Gulf of Venezuela. It is common around Florida, especially in enclosed waters such as the Indian River and among the islands off the southwestern coast. The Ladyfish also occurs around Bermuda, though not in any great numbers. To the north, it is present irregularly off Beaufort, North Carolina, and it has been reported as common in the Chesapeake Bay region; farther to the north its appearances—always in autumn—are sporadic. Considerable numbers were taken near Sandy Hook in October 1923; for example, 13 out of one trap on the 19th (*55*: 33). It has been recorded for the eastern part of Long Island (Orient), New York, from October 6 to November 4. Also, it has appeared in considerable numbers at various localities in the Woods Hole region in some autumns (*67*: 741), but there is no dependable record for a Ladyfish north of the elbow of Cape Cod—there is no knowing whether one taken at Chatham, Massachusetts, in 1888 (*7*: 139) was from Nantucket Sound or the Gulf of Maine shore of Cape Cod. Nor is there any possibility of determining whether an "*Albula vulpes*," taken at Black's Harbor (Charlotte County, New Brunswick) and in poor condition when examined (*31*: 45), was actually a Bonefish or Ladyfish.

Synonyms and References:

Elops saurus Linnaeus, Syst. Nat., ed. 12, 1766: 518 (orig. descr.; type local. "Carolina"; type, a dried skin in BMNH; see Goode and Bean, Proc. U.S. nat. Mus. [1885], *8*, 1886: 205); Bloch and Schneider, Syst. Ichthyol., 1801: 430, pl. 82 (descr., refs.); DeKay, New York Fauna, Fishes (4), 1842: 267, pl. 41, fig. 131 (descr., New York Harbor); Storer, Synop. Fish. N. Amer., 1846: 211 (descr., refs.); Gronow, Cat. Fish., Gray ed., 1854: 168 (descr., refs., distr.); Poey, Repert. Fisico-Nat. Cuba, *2*, 1867: 423 (diagn., Cuba); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 470 (synon., descr., Cuba, Jamaica, St.

Croix, "South America"; also several African and oriental locals. that probably are not this species); Yarrow, Proc. Acad. nat. Sci. Philad., 1877: 215 (Ft. Macon, North Carolina); Jordan and Gilbert (part not of Linnaeus), Bull. U.S. nat. Mus., *16*, 1883: 261 (diagn., range); Goode and Bean, Proc. U.S. nat. Mus. (1885), *8*, 1886: 205 (type, a dried skin cut in two pieces, in BMNH in Linnaean Soc. rooms); Willcox, Bull. U.S. Fish Comm. (1886), *6*, 1887: 123 (killed by cold, Florida); Henshall, Bull. U.S. Fish Comm. (1889), *9*, 1891: 373 (leptocephali, Marco, Florida); B. A. Bean, Proc. U.S. nat. Mus., *14*, 1891: 93 (Cape Charles, Virginia); Henshall, Bull. U.S. Fish Comm. (1894), *14*, 1895: 211 (Key West and Tampa, Florida; not as common as *Albula*; no econ. import.); Jordan and Evermann (part not of Linnaeus), Bull. U.S. nat. Mus., 47(*1*), 1896: 410 (descr., Amer. range includ. Pacif. cst., which has distinct species, *E. affinis* Regan); also 47 (*3*), 1898: 2806 (confusion of species); also *47* (*4*), 1900: fig. 178; Jordan and Rutter, Proc. Acad. nat. Sci. Philad., 1897: 94 (Jamaica, "sometimes 20 pounds" evidentally an error); Smith, Bull. U.S. Fish Comm. (1897), *17*, 1898: 90 (common in fall, Woods Hole, Massachusetts); Günther, Proc. linn. Soc. Lond., 1899: 25 (type in Linnaean Soc. coll.); Evermann and Kendall, Rep. U.S. Comm. Fish. (1899), 1900: 54 (Florida); Evermann and Marsh, Bull. U.S. Fish Comm. (1900), *20* (1), 1902: 81, fig. 11 (descr., Puerto Rico); Bean, Bull. N.Y. St. Mus., *60*, Zool. 9, 1903: 179 (refs., descr., New York); Schreiner and Ribiero, Arch. Mus. nac. Rio de J., *12*, 1903: 90 (Caravelas and Rio de Janeiro, Brazil; Woods Hole, Mass.); Hargraves, Fish. Brit. Guiana, 1906: 6 (local name "Long John"); Gill, Smithson. misc. Coll., *48*, 1905: 34 (skull figured, range; *Elops* cf. *Megalops*); Jordan and Thompson, Bull. U.S. Bur. Fish. (1904), *24*, 1905: 232 (Tortugas, Florida); Linton, Bull. U.S. Bur. Fish. (1904), *24*, 1905: 352 (food, parasites); Bull. Mus. comp. Zool. Harv., *50*, 1906: 156 (Gulf of Mexico at Progreso, Yucatán); Smith, N. C. geol. econ. Surv., *2*, 1907: 116, fig. 37 (refs., descr., range, North Carolina); Linton, Proc. U.S. nat. Mus. (1907), *33*, 1908: 86 (Bermuda); Regan, Ann. Mag. nat. Hist., (8) *3*, 1909: 37 (distr. limited to Amer. Atlant. cst.; Pacif. cst. represent. *E. affinis*; Afric. represent. *E. senegalensis*); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 204 (Nantucket, Mass.; "South Carolina"; West Palm Beach, Florida; Santo Domingo; doubtfully from Jamaica, and Rio de J., Brazil); Weymouth, Proc. U.S. nat. Mus., *38*, 1911: 136 (Cameron, Louisiana); Nichols, Bull. Amer. Mus. nat. Hist., *31*, 1912: 181 (common in markets, Cuba); Sumner, Osburn, and Cole, Bull. U.S. Bur. Fish. (1911), *31* (2), 1913: 741 (Woods Hole area, Mass.); Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 8 (coast of Brazil; Lake Papary, Rio Grande do Norte); Metzelaar, Trop. Atlant. Visschen, 1919: 9 (Curaçao, Dutch W. I., unimport. as food); Fowler, Proc. biol. Soc. Wash., *33*, 1920: 147 (Cape May, New Jersey); Breder, Zoologica, N. Y., *2* (15), 1922: 336 (Sandy Hook Bay); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 175 (synon., descr., range, Panama); Linton, Proc. U.S. nat. Mus., *64*, 1924: 59 (parasites); Bigelow and Welsh, Bull. U.S. Bur. Fish. (1924), *40* (1), 1925: 90, ftn. (questions Halkett's [1913: 45] ident. of New Brunswick specimen): Breder, Zoologica, N.Y., *4* (4), 1925: 141 (common at Gatun Dam Spillway, Canal Zone); Nichols and Breder, Zoologica, N.Y. (1926), *9* (1), 1927: 33, fig. (Sandy Hook, New Jersey; Orient and New York, N.Y.; Woods Hole, Mass.; a fall visitor); Hildebrand and Schroeder, Bull. U.S. Bur. Fish. (1927), *43* (1), 1928: 79, fig. 40 (descr., range, Chesapeake Bay); Beebe and Tee-Van, Zoologica, N.Y., *10* (1), 1928: 32, fig. (diagn., range, "apparently rather rare" at Port-au-Prince, Haiti); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish. (1928), *2*, 1930: 39 (common names, range, synon.); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 60, fig. (diagn., range, size); Fowler, Proc. Acad. nat. Sci. Philad., *80*, 1929: 609 (Atlantic City, New Jersey); Jordan, Manual Vert. Anim. NE U.S., ed. 13, 1929: 36 (diagn., range); Nichols, N.Y. Acad. Sci., *10* (2), 1929: 119 (probably not uncommon in Puerto Rican waters; diagn.; excellent sport fish with light tackle); Fowler, Copeia, No. 2, 1931: 46 (Corpus Christi, Texas; local name skipjack); also Proc. Acad. nat. Sci. Philad., *83*: 1931: 392, fig. 1 (Trinidad); Beebe and Tee-Van, Field Bk. Shore Fish. Bermuda, 1933: 33, fig. (descr., rare in Bermuda); Fowler (part not *E. saurus* Linn.), Bull. Amer. Mus. nat. Hist., *70* (1), 1936: 155 (synon., includ. Afric. refs. based on *E. senegalensis* Regan; descr. based in part on Afric. specimen); Hollister, Zoologica, N.Y., *21* (4), 1936: 260–263, figs. (caudal skel.); Hildebrand, Sci. Month., *44*, 1937: 243 (abund. in Gatun Locks, Panama Canal, when drained); Kaplan, Big Game Angler's Paradise, 1937: 91 (size, food, called Ladyfish in Florida); Storey, Ecology, *18*, 1937: 16 (often hurt by freezes); Breder, Bull. N.Y. zool. Soc., *41*, 1938: 24 (irregular, New York Harbor); Hildebrand, Zoologica, N.Y., *24* (1), 1939: 25 (Gatun Locks, Panama Canal, apparently feed. ground); Merriman, Copeia, 1939: 113, figs. A–D (scales); Bigelow and Schroeder, Copeia, 1940: 139 (Chatham, Cape Cod, Mass., northernmost definite rec.); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 4 (rare at Tortugas, Florida); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 132 (refs.); Hildebrand, J. Wash. Acad. Sci., *33* (3), 1943: 90–94, 3 figs. (notes on affinity, anat., develop.).

gentina carolina Linnaeus, Syst. Nat., ed 12, 1766: 519 (orig. descr.; type local. "Carolina"; type lost).

gilomorus anna-carolina Lacépède, Hist. Nat. Poiss., 5, 1803: 398 (orig. descr.; type local. "South Carolina"; type in Paris).

ps inermis Mitchill, Rep. in part on Fish. New York, 1814: 14 (orig. descr.; type local. New York, specimen secured in market; type lost); Mitchill, Trans. Lit. philos. Soc. N.Y., 1815: 445 (descr., New York).

ula vulpes Gregg (not *A. vulpes* Linnaeus, but *Elops saurus*), Where to Catch Fish E. Cst. Fla., 1902: 34 (descr., instruct. for angling, barely edible).

ubtful Reference:

ps saurus Halkett, Check List Fish. Canada, 1913: 45 (report. New Brunswick; ident. doubtful).

gative References:[10]

ps saurus Gregg, Where to Catch Fish. E. Cst. Fla., 1902: 33, fig. (*Albula vulpes*, not *E. saurus*); Bean, Bahama Islands: Fishes, 1905: 297 (determined as small *Jenkinsia lamprotaenia* on re-exam. by present writer; not *E. saurus*; USNM 53076).

To these may be added all mention of *Elops saurus* based on specimens not taken on the Atlantic coast of America, of which there are many.

Family Albulidae[11]

SAMUEL F. HILDEBRAND[12]

Characters. Body slender, little compressed; belly rounded; ordinary scales on median line. Head rather low; flat above. Snout conical, projecting far in advance of mandible. Eye of moderate size, with much adipose tissue in adults. Mouth moderately small, nearly horizontal. Maxillary generally reaching nearly to front of eye, or to some point underneath it, but never beyond eye. Premaxillaries not protractile. Gular plate lacking. Teeth small, present in bands on jaws, vomer, palatines, pterygoids, basibranchials, and sphenoid. Branchiostegals 13 or 14. Gill membranes separate, free from isthmus; a membrane across isthmus in front. Opercular bones with membranous borders. Pseudobranchiae well developed. Gill rakers very short, stout, tubercular in large examples. Last several segments of Spinal column directed upward toward base of upper lobe of caudal. Lateral line present, straight. Scales of moderate size, more or less quadrate, with membranous border, 3 (rarely 4) nearly parallel basal radii, and 4 or 5 coarse basal lobes (fully described by Cockerell, *15*: 3; *16*: 865; *17*: 122); scales extending onto the fins; a modified median row of enlarged scales in front of dorsal fin; no scales on head. Dorsal fin beginning in advance of pelvics. Caudal forked. Anal very small, placed far behind dorsal. Pectorals and Pelvics similar, each with an Axillary scale.

The young pass through a leptocephalus stage like the Elopidae and the eels.[13]

Remarks. The members of this family differ from those of Elopidae principally in the absence of a gular plate, and in having a conical snout as well as fewer bran-

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[11] Edited and emended by George S. Myers, Henry B. Bigelow, and Yngve H. Olsen.

[12] August 15, 1883–March 16, 1949.

[13] The heart of *Albula* is reminiscent of the ganoids in having a rudimentary conus arteriosus with two rows of valves (*9*: 548). Several fossil albulids are known, from as far back as the Eocene (*54*: 84).—G.S.M.

535, 1941: 4 (rare at Tortugas, Florida); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 132 (refs.); Hildebrand, J. Wash. Acad. Sci., *33* (3), 1943: 90–94, 3 figs. (notes on affinity, anat., develop.).

Argentina carolina Linnaeus, Syst. Nat., ed 12, 1766: 519 (orig. descr.; type local. "Carolina"; type lost).

Mugilomorus anna-carolina Lacépède, Hist. Nat. Poiss., 5, 1803: 398 (orig. descr.; type local. "South Carolina"; type in Paris).

Elops inermis Mitchill, Rep. in part on Fish. New York, 1814: 14 (orig. descr.; type local. New York, specimen secured in market; type lost); Mitchill, Trans. Lit. philos. Soc. N.Y., 1815: 445 (descr., New York).

Albula vulpes Gregg (not *A. vulpes* Linnaeus, but *Elops saurus*), Where to Catch Fish E. Cst. Fla., 1902: 34 (descr., instruct. for angling, barely edible).

Doubtful Reference:

Elops saurus Halkett, Check List Fish. Canada, 1913: 45 (report. New Brunswick; ident. doubtful).

Negative References:[10]

Elops saurus Gregg, Where to Catch Fish. E. Cst. Fla., 1902: 33, fig. (*Albula vulpes*, not *E. saurus*); Bean, Bahama Islands: Fishes, 1905: 297 (determined as small *Jenkinsia lamprotaenia* on re-exam. by present writer; not *E. saurus*; USNM 53076).

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[10] To these may be added all mention of *Elops saurus* based on specimens not taken on the Atlantic coast of America, of which there are many.

chiostegals (13 or 14). From members of the Clupeidae they differ in having a well-developed lateral line and undeveloped gill rakers.

Range. Only two living genera, *Albula* and *Dixonina*, are recognized.[14] The former has a world-wide distribution in warmer seas, and the latter is known from both coasts of tropical America.

Key to Western Atlantic Genera

1a. Last ray of dorsal and anal not prolonged; snout only moderately conical, projecting only about a third of its length beyond mandible; maxillary not reaching eye. *Albula* Scopoli 1777, below.

1b. Last ray of dorsal and anal much prolonged; snout sharply conical, projecting more than a third of its length beyond mandible; maxillary reaching nearly to middle of eye. *Dixonina* Fowler 1911, p. 143.

Genus *Albula* Scopoli 1777

Bonefishes

Albula Scopoli, Introd. Hist. Nat., 1777: 450; no species named, but based on *Albula* (name not binomial; followed by long description), in Gronow, Zoophyl., *1*, 1763: 102; type and only included species Albula s. salmo albula Meuschen, in Gronow, *3*, 1761, index (not paged), Mediterranean; binomial name given to Gronow's (1763) *Albula* (Whitley, *72*: 303) equals *Esox vulpes* Linnaeus, Syst. Nat., 1758: 313.

Generic Synonyms:

Esox, in part, Linnaeus, Syst. Nat., *1*, 1758: 313, for *E. vulpes* Linnaeus, Bahamas.

Argentina, in part, Forskål, Descr. Anim ..., 1775: 68, for *A. glossodonta* Forskål, Arabia.

Amia, in part, Bloch and Schneider, Syst. Ichthyol., 1801: 457, for *A. immaculata* Bloch and Schneider, South America.

Synodus, in part, Bloch and Schneider, Syst. Ichthyol., 1801: 398, for *S. argenteus* Bloch and Schneider, Tahiti; Lacépède, Hist. Nat. Poiss., *5*, 1803: 32, pl. 8, fig. 2, for *S. vulpes* Lacépède.

Clupea, in part, Bloch and Schneider, Syst. Ichthyol., 1801: 427, for *C. brasiliensis* Bloch and Schneider, Brazil; Lacépède, Hist. Nat. Poiss., *5*, 1803: 427, for *C. macrocephala* Lacépède, Martinique.

Butyrinus Lacépède, Hist. Nat. Poiss., *5*, 1803: 45; type by monotypy, *Butyrinus bananus* Lacépède equals *Esox vulpes* Linnaeus.

Glossodus Cuvier, Mem. Mus. Hist. nat. Paris, *1*, 1815: 232; genotype by monotypy, *Argentina glossodonta* Forskål equals *Esox vulpes* Linnaeus.

Engraulis Agassiz, L. *in* Spix and Agassiz, Selecta genera et species piscium... Brazil..., 1829: pl. 23, fig. 2, for *E. sericus* Agassiz; pl. 24, fig. 2, for *E. bahiensis* Agassiz, Brazil.

Conorhynchus Gill, Proc. Acad. nat. Sci. Philad., Suppl., 1861: 55; genotype by monotypy, *Butirinus vulpes* Storer equals *Albula vulpes*.

Characters. DORSAL and ANAL fins with the last ray not produced. MAXILLARY falling short of vertical from front border of eye. SNOUT projecting about a third of its

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[14] Dr. Hildebrand evidently excluded from the Albulidae the deep-water genus *Pterothrissus*, which is known from the coasts of Japan and West Africa and which may eventually be found in the western North Atlantic. *Pterothrissus* differs widely from *Albula* and *Dixonina* in the very long, many-rayed dorsal fin.—G. S. Myers.

length beyond tip of lower jaw. Caudal skeleton (*39*: 269–275) exhibiting some ganoid characters, showing a relationship with that primitive group. Vertebrae: last 2 or 3 in *A. vulpes* out of line with central axis, directed somewhat dorsally; massive spines (neurals) attached to them and preceding segment, extending into base of upper lobe of caudal. Alimentary canal appearing as a straight tube in larvae, becoming modified in the adult with development of a very large stomach that occupies fully 67 % of the length of abdominal cavity if distended with food; stomach largely a blind sac; the cardiac and pyloric orifices rather close together. About 13 Pyloric coeca, bound together, forming a sort of sheath over part of stomach. Air bladder very long, extending backward far beyond vent, its walls very thin, without lung tissue (see tarpon) except for a pair of very small kidney-shaped cellular bodies attached ventrally at about midlength.

Remarks. This genus differs from *Dixonina* chiefly in that the last ray of both dorsal and anal is short and does not become prolonged in adults; see also Key, p. 133. From *Elops* it is distinguishable by the absence of a gular plate (p. 123).

Range. Only one modern species, *Albula vulpes*, is generally recognized; this occurs in virtually all warm seas.

Albula vulpes (Linnaeus) 1758

Bonefish, Grubber, Bananafish

Figures 22, 23

Study Material. An almost complete growth series ranging from leptocephali with virtually undeveloped dorsal and anal fins to adults 430 mm TL, from both Atlantic and Pacific. As the growth series was not complete in the material from the Atlantic, some specimens, especially the older stages of leptocephali and first stages of young adults, from the Pearl Islands in Panama Bay, were used in describing the young.

Distinctive Characters. See *Remarks*, above.

Description. Proportional dimensions in per cent of standard length, and counts, based on Atlantic adults only.

Body: depth at origin of dorsal 20–23 in large specimens, 14–19 in young adults.
Caudal peduncle: depth 6.9–8.9.
Head: length 27.5–32.
Snout: length 11.5–13.6 in large specimens, 8.5–10 in young adults.
Eye: diameter 5.5–8.0
Maxillary: length from tip of snout 9.1–12.7.
Anal fin: length of base 5.1–6.75.
Pectoral fin: length 15–19.
Scales: 65–71.
Gill rakers: 7 or 8+9 or 10.
Fin rays: dorsal 17 or 18, rarely 19; anal 8 or 9; pectoral 16 or 17, rarely 15.
Vertebrae: 72–74 (5 specimens).

Body slender, rounder and less compressed in large specimens than in young adults, its dorsal profile more convex than ventral profile, its depth at dorsal origin 4.35–4.9 in SL in large specimens, about 5.25–7.1 in the more slender, recently-metamorphosed young. Scales firm, with crenulate membranous edges. Head low, especially in large specimens, flat above, its depth exceeding its width at middle of eye by about diameter of pupil, 3.0–3.8 in SL. Snout rather long, conical, especially in large specimens, projecting about a third of its length beyond mandible, 2.2–2.5 in head, about 2.7–3.5 in young adults. Eye moderately small, 4.4–5.5 in head, its center nearer to margin of opercle than to tip of snout. Maxillary not quite reaching to eye in large specimens, but extending to, or slightly beyond, anterior margin of eye in young adults, 2.6–3.15 in head (measured from tip of snout).

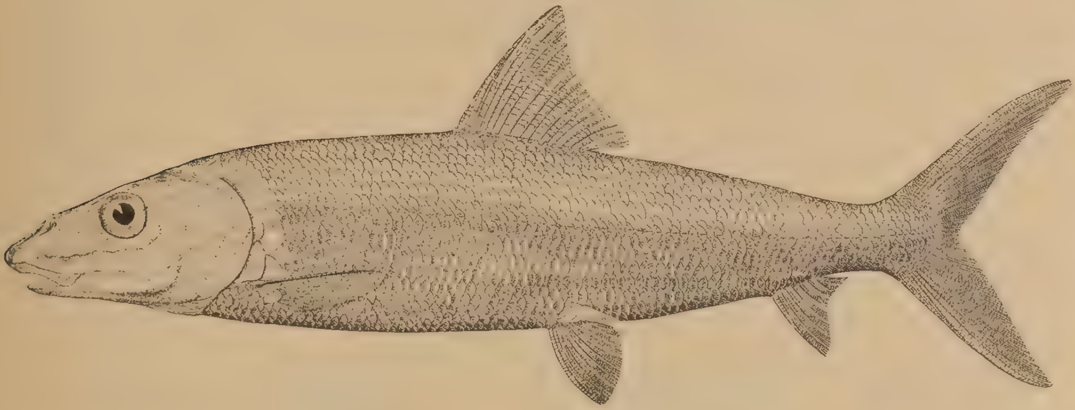

Figure 22. *Albula vulpes*, from off Newport, Rhode Island; from Goode. Drawn by H. L. Todd.

Dorsal fin somewhat elevated anteriorly, its longest rays not reaching to tip of posterior ray if deflexed, its origin a little nearer to tip of snout than to base of caudal. Caudal deeply forked, the upper lobe somewhat longer than the lower. Anal very small, its origin notably nearer to base of caudal than to base of pelvic, its last ray, though longer than the preceding one, not especially produced, its base 4.7–5.4 in head. Pelvic somewhat smaller than pectoral, inserted under or slightly behind middle of dorsal base. Pectoral with rounded margin, reaching notably less than halfway to pelvic, 1.7–2.0 in head. Axillary scale of pectoral about half as long as fin, adherent to body.

Color. Large specimens bluish above; bright silvery on sides and below; dark streaks between rows of scales, at least on dorsal half of side; dorsal and caudal with dusky margins, frequently entirely pale in preserved specimens. Very young adults (completely metamorphosed and about 30 mm) with a double series of dark spots on the back, each just off the median line; these spots soon uniting to form about nine dark crossbands on the back, extending down nearly or quite to lateral line; the third band crossing back at origin of dorsal; next two situated posteriorly under base of dorsal;

bands persisting until a length of about 75 mm. The dark longitudinal streaks of the adults appearing shortly before crossbands become obscure.

Size. Its maximum length is about 770 mm (31 in.) and its weight about 13 or 14 pounds.

Development.[15] The eggs and the earliest stages of the leptocephali remain unknown. The youngest at hand, that is, the least developed larva, is apparently somewhat younger than any yet described. It is 57 mm long (51 mm SL), was collected at Tortugas, Florida, and is the only one of the many that has the dorsal and anal fins entirely undeveloped. The pectoral fins appear as mere tufts of membrane and the pelvics only as a thickening of the body wall where the bases are developing. The caudal fin, however, is well developed with segmented rays, is broadly forked, and is about as long as the head. This larva is sharply compressed, though not more so than considerably older ones; its depth increases gradually backward from the head to about the beginning of the distal fourth of the body, where it is contained 11.8 times in SL. Myomeres are prominent, except anteriorly and posteriorly, and about 66 may be counted. The head is low and moderately broad and is contained 16.4 times in SL. The snout is conical and projects slightly beyond the mandible, the maxillary is not definitely formed, the slightly oblique gape extends under the anterior part of the eye, and the eye is scarcely as long as the snout, being contained in the head 4.1 times. The intestinal tract appears to be a straight tube, is rather loosely attached to the body, has a slight groove on each side, and extends nearly to the base of the lower lobe of the caudal. This old preserved specimen, collected in 1919, is now entirely without pigment. Several other specimens from Tortugas and Cuba are only slightly more developed.

Although leptocephali 75–87 mm long have been reported (*28*: 40),[16] the largest one now at hand among several hundred from many localities along the Atlantic and Pacific coasts of America is just 70 mm long (57 mm SL). In this specimen, one of a large collection from the Pearl Islands, Panama Bay, the dorsal and anal fins are developed (showing at least most of the rays), and the fulcra may be fairly accurately enumerated. The dorsal fin is placed over about the beginning of the distal fifth of the body. The anal is scarcely separated from the base of the lower caudal lobe. The pelvic fins are developed but do not have definite rays and are placed at about midbody length without the head, a position retained throughout life. The pectoral fins are fairly long, with definite indications of rays. The body is deepest somewhat in advance of the dorsal fin, and its depth there is contained 9.25 times in SL; 69 myomeres were counted. No prominent changes in the head region are evident. The head is contained 14.4 times in the SL. The snout and eye are of about equal length, being 3.6 in head. The jaws possess minute teeth that project somewhat forward. Two almost continuous dotted dark lines bound the intestinal tract from behind the pectoral fins to the vent, being interrupted only at the point of insertion of the pelvics; and a vertical series of dark dots is present on the caudal base. Living larvae of this size, and considerably older ones as well, are as transparent as glass. They appear as shining objects in the net and are easily overlooked, only the dark eyes being at all conspicuous.

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[15] A detailed account of the development and distribution of young *Albula*, based on the DANA collections, has recently been published by Alexander (DANA Rep., *53*, 1961).

[16] The fact that *Albula* has a "leptocephalus" larva was first ascertained about 1896 by Prof. C. H. Gilbert of Stanford University. It seems he never published an account himself, but a synopsis of his findings, with his figures of the developmental stages, was made known by Jordan (*44*) and Gill (*28*: 43) — G. S. Myers.

Older larvae of 45 mm (39 mm SL), though still sharply compressed, are much more substantial than younger ones at a length of 70 mm or so. The dorsal and anal fins have moved forward considerably, the anal fin now being separated from the caudal by at least half the length of the head. The greatest body depth, at the origin of the dorsal, is contained 7.6 times in SL. The myomeres total 70–72. The head remains rather low and broad and is contained 6.0 times in the length; the snout projects beyond the mandible more prominently and is now rather longer than the eye, 4.0 times in head; and the maxillary is fairly well developed, extending well beyond the anterior margin of the eye, 2.4 in head. The color remains as in the younger fish described, except that a few dark chromatophores have appeared about the head, and a slightly broken dark line has developed on both upper and lower lobes of the caudal.

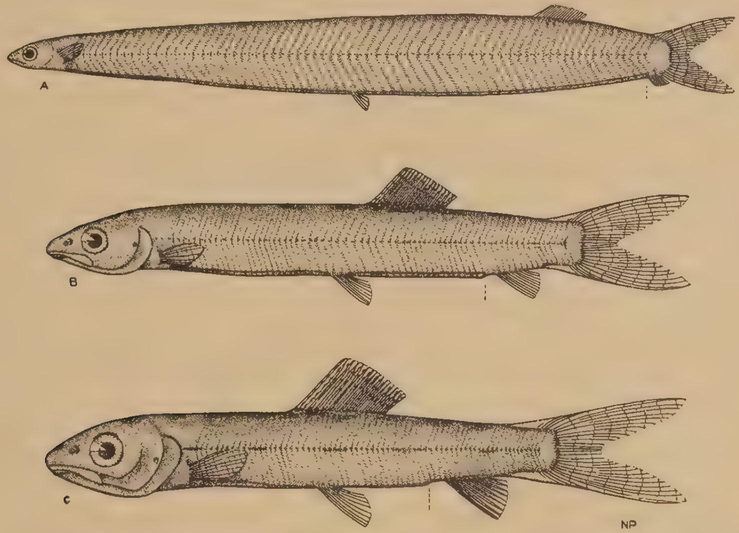

FIGURE 23. *Albula vulpes*. Pearl Island, Pacific Panama, USNM 128391. A Leptocephalus stage, 68 mm long; B older larva in transition stage, 76 mm TL; C older fry 30 mm TL. Drawn by Nancy D. Patton.

Larvae 32 mm long (26 mm SL) are the smallest in the study collections that may be classed as leptocephali. The body remains strongly compressed, though of course more robust and more substantial than in the 45-mm fish described above, and it has become more elongate, the depth at the dorsal origin being contained 8.4 times in SL. The dorsal and anal fins have continued to move forward, but they still remain more posteriorly placed than in the adult; the origin of the dorsal is somewhat nearer to the base of the caudal than to the tip of the snout and is approximately over the pelvic fins. The intestinal tract has become more fully invaginated and no longer remains merely attached, except posteriorly, as in younger fish; the vent, instead of being situated at the origin of the anal, is now well in advance of it, having moved forward rather more rapidly than the fin. The color markings remain about as in the younger fish described, but additional chromatophores have appeared, principally at the occiput, at the base of the dorsal, and on the dorsal.

The smallest specimen that may be classed as a young adult is 28 mm (21 mm SL), and its length is the least of the many *Albula* at hand. This fish is quite a little longer than the one that diminished from a leptocephalus to a young adult of only 20 mm, in an aquarium (*39*: 269; *40*: 109). The body remains more compressed in this and other young adults than in large adults, and it is also more slender, the depth at the dorsal origin 6.5 times in SL. The head is contained 3.45 times in SL and therefore does not differ in this proportion from large adults. The eye is rather small, 5.05 times in head, and is definitely shorter than the snout, which is contained 3.05 times in the head and projects rather prominently beyond the mandible; the maxillary extends to the anterior margin of the pupil and is contained 2.9 times in head. The dorsal and anal fins have continued to move forward, the origin of the dorsal now being equidistant between base of caudal and tip of snout; and the attachment of the pelvic fins is now only a little in advance of the middle of the dorsal base. At this stage, and even in ones a little older, the two dark lines along the sides of the intestinal tract in the leptocephali persist, two rows of dark spots on the back (described elsewhere) have appeared, there are indications of some elongate dark spots along the side, and some additional pigment has appeared on the base of the anal and ventrally on the caudal peduncle.

Scales first appear in young adults about 35 mm long. At a length of 40–45 mm, scalation generally is complete, except perhaps on the abdomen. At these stages the lateral line also is well developed. The dorsal and anal fins are situated approximately as in large adults; that is, the origin of the dorsal is somewhat nearer to the tip of the snout than to the base of caudal, and the anal is separated from the caudal by a distance somewhat greater than the length of the snout. The pelvic fins, which, from the time of their appearance in the leptocephalus, are inserted a little nearer to the head than to the base of caudal, retain that relative position and are now about under the middle of the dorsal base. The pectorals are long but not falcate and reach more than halfway to the pelvics. The vent has continued to move forward and is now in advance of the anal by a distance nearly equal to the length of the snout.

At 40 mm, pigmentation has become general and the nine crossbands on the back, described elsewhere, are prominent. But dark longitudinal stripes do not appear definitely until a length of about 75 mm is attained, at which size the crossbands have become obscure.

Spawning. The spawning season and the spawning grounds remain unknown. Most of the many larvae and young adults described herein were taken off the coast of Panama during February and March, but their occurrence at other seasons is not known, as no year-round collecting has been done there. Growth stages ranging from fairly young leptocephali of 70 mm TL to young adults 52 mm long were exceedingly numerous among some of the Pacific islands in Panama Bay in March 1937 (especially in the Pearl Islands). Somewhat similar stages, though less numerous, were taken in February and March on the Atlantic coast of Panama. Other leptocephali at hand were taken as follows: January 23 on the Pacific coast of Colombia, February 13 in Puerto Rico, March 13 in the Virgin Islands, April 8 in Cuba, April 23 and 28 in Haiti, May 19 in Cuba, June 30 at Beaufort, N.C., July 21 in Bermuda, and August 7 and November 25 at Tortugas, Florida. Beebe and Tee-Van (*5*: 37) have reported that on 34 evenings of collecting (between February 26 and April 30) with an electric light lowered from the gangway of a schooner in Port-au-Prince Bay, Haiti, larvae of *Albula* were absent only two nights and were very abundant 17 nights. With the capture of the leptocephali spread over most of the year and at widely spaced localities, there is little indication of where and when spawning takes place.

Although an advanced leptocephalus transformed rapidly in an aquarium under observation (*39*: 269; *40*: 109), it cannot be concluded that development before capture was equally fast, and that the rapid transformation under artificial conditions was normal, especially in the light of what is known about the slow development of the leptocephali of freshwater eels. At least the possibility exists that the rather advanced leptocephali that have been described may have been several months old and were caught far from the place where they had hatched.

Habits. The adult is usually caught in comparatively shallow water, but to what extent it enters deep water offshore apparently has not been determined. The larva has been taken at night at the surface under an electric light, by which it seems to be attracted, and during the day in the shallow water of bays and estuaries with seines, at least once in a creek with nearly fresh water (in Panama), and on one occasion in the surf on the outer shores of Bogue Banks, North Carolina. During March 1937, the larva and young adult were found in great abundance among islands in Panama Bay. In one very shallow tide pool with a muddy bottom, off San José Island in the Pearl Islands group, the water was literally "soupy" with fish and crustaceans. At the time there was an exceptionally low tide, and the concentration was so great and the water so shallow and warm that many small shrimp and fish perished, but the greater part of the aggregation seemed to endure the situation. It was possible to select from this pool a growth series ranging from leptocephali 70 mm long, the youngest present, to young adults 52 mm long.

Food. This fish, known as the Grubber in Bermuda (*40*: 104) grubs up some of its food from the bottom with its nose and sometimes turns somersaults in the process. In the West Indies and Florida it may be seen by day (*53*: 187), along shallow sandbanks and among underwater grasses, feeding during incoming tides on worms, mollusks, and crabs; but in Bermuda it apparently comes into the shallows at night to feed. Bivalves and small squid have been reported as its food (*5*: 37). In the Pearl Islands, young adults were gorged with small shrimp, but a few fish (small atherinids) had been eaten also.

Relationship and Variation. Only one species has been recognized. Insufficient material from its wide range has been studied, but the present study of specimens from the Atlantic and Pacific coasts of America has shown no constant differences or variations of importance.

Relation to Man. This species is not considered a good foodfish in most of its range in America. Schroeder, reporting on the fisheries at Key West, Florida, stated that "it is not highly regarded as a foodfish, and its commercial value is negligible" (*61*: 4). Similar statements are included in publications about the fishes of the West Indies. But Hollister, presumably reporting on observations made in Bermuda, stated to the contrary that "it surpasses its famous cousin, the Silver King, or tarpon, in possessing a combination of qualities, that of gaminess and of being a table delicacy" (*40*: 104). From the writer's own observations in Panama, the Bonefish is considered an inferior foodfish, whereas the tarpon is highly regarded as food by the native population. Thus tastes seem to differ in different localities.

However, the Bonefish ranks high with anglers, especially around Florida and the Bahamas, for it is so wary when feeding on the flats that careful stalking and long and delicate casting are called for; but once hooked, its runs are longer and swifter and its resistance far more vigorous and indefatigable than one might expect from such a comparatively small fish.

Miss Francesca LaMonte of the American Museum of Natural History, long acquainted with the sport fisheries, has generously offered the following information: This warm-water fish, which provides splendid angling with simple equipment, is caught on the flats and can be fished there either from a boat or while wading. The boat should be light as well as flat-bottomed and should be provided with an outboard motor, oars, and anchors for both bow and stern. The fish is taken by casting or still fishing, but the favorite method is casting. Light tackle with plug casting or saltwater fly rod provides good sport. As bait, anglers may use conch, crabs or crayfish, feathers, lures, or squid. Coming in with the tide, the Bonefish spreads out over the flats and among the mangrove stands; when the tide ebbs, it seeks deep holes. On the flats, the angler may chum or get his bait into the middle of a "mud" or group of Bonefish that is feeding, with tails uppermost while grubbing on the bottom.

When hooked, the Bonefish makes a very fast and strong run, taking out yards of line. In so doing it varies the straight dash by suddenly turning and coming toward the boat or by running into the mangroves where the line may be cut on the roots. After making several of these runs, the Bonefish usually begins to wear out, begins circling the boat, and can finally be picked up in a landing net.

For many years the angling record stood at 13¾ pounds for one caught on the famous Bonefish grounds off Bimini in the northern Bahama Islands, but this record was eventually beaten. The present record is for a fish of 18 pounds 2 ounces, caught off Kauai, Hawaiian Islands. In the western North Atlantic, the best known Bonefish grounds are the Florida Keys near Miami, the Islamorada-Marathon area, and the northern Bahamas.

Range and Abundance. The Bonefish is known from virtually all warm seas. On the Atlantic coast of America it is plentiful around southern Florida, among the northern Bahamas, and around Bermuda. But its area of chief abundance evidently does not reach much farther to the north, for it is rare even at Beaufort, North Carolina. However, odd specimens have been reported for the vicinity of New York (*2*: 183), Newport, Rhode Island (*68*: 74), the vicinity of Woods Hole, Massachusetts (*67*: 741), and perhaps even Charlotte County, New Brunswick, at the mouth of the Bay of Fundy (ftn. 15).

To the south it is present more or less regularly in the West Indies and on the Atlantic coast of Panama, though it does not seem to be numerous; it is known from as far south as Rio de Janeiro. On the Pacific coast of America it has been reported as occurring from San Francisco Bay, California, to Talara, Peru.

Synonyms and References:[17]

Esox vulpes Linnaeus, Syst. Nat., ed. 10, 1758: 313 (orig. descr.; based on *Vulpes bahamensis* Catesby, pre-Linnaean; type local. Bahamas; no type specimen).

Albula s. *Salmo albula* (nec *Salmo albula* Linnaeus) Meuschen, in Gronow, Zoophyl., *3*, 1781: index, unpaged (on "*Albula*" Gronow; type local. Mediterranean; type lost).

Clupea brasiliensis Bloch and Schneider, Syst. Ichthyol., 1801: 427 (orig. descr.; type local. Brazil; based on Marcgrave's MSS. in Berlin).

Albula conorhynchus Bloch and Schneider, Syst. Ichthyol., 1801: 432, pl. 86 (orig. descr.; based on Gronow, Plumier, and Marcgrave; no special type local. except Medit. and Amer.); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 468 (descr., synon., Amer. locals.—West Indies, Jamaica, Belize, Puerto Cabello, Bahia, Natal, and Pacif. cst. of Centr. Amer.); Yarrow, Proc. Acad. nat. Sci. Philad., 1877: 215 (Ft. Macon, North Carolina).

Albula plumieri Bloch and Schneider, Syst. Ichthyol., 1801: pl. 86 (name on plate only; LAPSUS for *conorhynchus*).

Amia immaculata Bloch and Schneider, Syst. Ichthyol., 1801: 451 (orig. descr., after *Macabi* Parra [1787: 88, pl. 35, fig., nonbinomial]; type local. S. Amer.).

Clupea macrocephala Lacépède, Hist. Nat. Poiss., *5*, 1803: 426 (orig. descr.; type local. Martinique; after Plumier fig.).

Glossodus forskåli Agassiz, in Spix and Agassiz, Pisc. Brasil, 1829: 49; called *Engraulis sericus* on pl. 23 and *E. bahiensis* on pl. 24, fig. 2 (orig. descr.; type local. Bahia, Brazil; type probably in Munich).

Albula parrae Cuvier and Valenciennes, Hist. Nat. Poiss., *19*, 1846: 339 (orig. descr.; type local. Bahia and Rio de Janeiro, Brazil; type in Paris).

Butirinus vulpes Storer, Synop. Fish. N. Amer., 1846: 212 (diagn., refs.).

Albula rostrata Gronow, Cat. Fish., Gray ed., 1854: 189 (orig. descr.; type locals. Amer. and Indian oceans, Medit. Sea; type probably in London).

Conorhynchus plumieri Poey, Repert. Fisico-Nat. Cuba, *2*, 1867: 423 (descr., Cuba).

Albula vulpes Jordan and Gilbert, Bull. U.S. nat. Mus., *16*, 1883: 258 (descr., range); Bean, Bull. U.S. Fish Comm. (1888), *8*, 1890: 206 (not uncommon at Cozumel, Yucatán); Collins and Smith, Bull. U.S. Fish Comm. (1891), *11*, 1892: 104 (commerc. catch, Gulf coast, Florida, 1890); Eigenmann, Proc. U.S. nat. Mus. (1892), *15*, 1893: 135 (not abund. at San Diego, California); Henshall, Bull. U.S. Fish Comm. (1894), *14*, 1895: 211 (common at keys, passes, inlets of s. Florida, good food and game fish); Lönnberg, Ofvers. Svensk. Vet. Akad. Forh., 9, 1895: 662 (Cape Haitien, Haiti); Jordan and Evermann, Bull. U.S. nat. Mus., 47 (*1*), 1896: 411; 47 (*4*), 1900: fig. 179 (descr., range, synon.); Jordan and Rutter, Proc. Acad. nat. Sci. Philad., 1897: 94 (Jamaica); Smith, Bull. U.S. Fish Comm. (1897), *17*, 1898: 91 (rare at Woods Hole, Massachusetts); Evermann and Kendall, Rep. U.S. Comm. Fish. (1899), 1900: 55 (Florida); Gilbert, Proc. Wash. Acad. Sci., *2*, 1900: 163 (Pernambuco and Maceió, Brazil);

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[17] Literature dealing with American specimens only, or in part, is cited. It does not seem necessary to cite Old World references here.

Evermann and Marsh, Bull. U.S. Fish Comm. (1900), *20* (1), 1902: 82 (descr. range, econ. import., Puerto Rico); Bean, Bull. N.Y. St. Mus., *60*, Zool. 9, 1903: 182 (synon., descr., range, New York and elsewhere); Bean, Field Mus. Publ., Zool., *7*, 1906; 33 (5 Bermuda locals.); Gilbert and Starks, Mem. Cal. Acad. Sci., *4*, 1904: 39 (in Panama City market); Jordan and Thompson, Bull. U.S. Bur. Fish. (1904), *24*, 1905: 232 (Tortugas, Florida; discus.); Gill, Smithson. misc. Coll., *48*, 1905: 40 (descr. and figs. of skull, develop. of leptocephali, habitat, game qualities; C. H. Gilbert discovered leptocephalus stage); Bean, Bahama Is., Fish., 1905: 297 (Spanish Wells, Bahamas); Smith, N.C. geol. econ. Surv., *2*, 1907: 117 (synon., diagn., U.S. coasts, esp. North Carolina); Coles, Bull. Amer. Mus. nat. Hist., *28*, 1910: 344 (Cape Lookout, North Carolina); Cockerell, Smithson. misc. Coll., *56* (3), 1911: 3 (scale descr.); Bull. U.S. Bur. Fish. (1912), *32*, 1913: 122, fig. 2 (scales not different from those of *Dixonina*; similar to *Synodus* and *Esox*); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 204 (Santo Domingo, St. Martin, Jamaica); Nichols, Bull. Amer. Mus. nat. Hist., *31*, 1912: 181 (not uncommon in Havana, Cuba, market); Gudger, J. Mitchell Sci. Soc., *28*, 1913: 166 (rare, Beaufort, North Carolina); Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 8 (Natal, Brazil); Sumner, Osburn, and Cole, Bull. U.S. Bur. Fish. (1911), *31* (2), 1913: 741 (rare at Woods Hole, Mass.); Halkett, Check List Fish. Canada, 1913: 45 (Bay of Fundy, New Brunswick); Weber and de Beaufort, Fish. Indo-Aust. Archipelago, *2*, 1913: 7, fig. 5 (synon., descr., develop. of leptocephali; figs. of leptocephali labeled "after Gilbert," but without citation to Gilbert; figs. of larvae apparently after Gill, 1905); Fowler, Proc. Acad. nat. Sci. Philad., *67*, 1915: 522 (Trinidad, B. W. I.); *68*, 1916: 397 (Port Limon, Costa Rica); *69*, 1917: 128 (Colón, Panama); Metzelaar, Trop. Atlant. Vissch., 1919: 8 (St. Martin, and other Windward and Leeward islands; not common, not much used as food); Metzelaar, Bijdr. Dierk. K. zool. Genoot. Amst., 1922: 134 (Curaçao); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 178 (synon., descr., range, Panama); Schroeder, Rep. U.S. Comm. Fish. (1923), Append. 12, 1924: 4 (commerc. value, Key West, Florida); Mowbray, Book of Fishes, Nat. geogr. Soc., ed 1924: 135–137, color pl. on p. 122; ed. 1939: 186–187, color pl. on p. 201 (genl. accts.); Breder, Bull. Bingham oceanogr. Coll., *2* (2), 1928: 4 (young adult, Sonora, México; adult from Pearl Is., Panama); Nichols and Breder, Zoologica, N.Y., *9* (1), 1927: 34 (diagn., distr., life hist., size); Beebe and Tee-Van, Zoologica, N.Y., *10* (1), 1928: 37 (refs., field characters, size, color, range, uncommon at Port-au-Prince, Haiti); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 200 (distr., not uncommon in Puerto Rican waters, diagn., habits); Breder, Field Bk. Mar. Fish. Atlant. Cst., 1929: 60, fig. (diagn., abund., range, habits, size); Fowler, Proc. Acad. nat. Sci. Philad., *80*, 1929: 609 (Barnegat Inlet, Atlantic City, first definite recs. for New Jersey); Jordan, Manual Vert. Anim. NE U.S., 1929: 38 (diagn., range); Fowler, Proc. Acad. nat. Sci. Philad., *82*, 1930: 269 (Grenada, B. W. I.); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish. (1928), *2*, 1930: 39 (range, synon.); Gowanloch, Bull. La. Conserv. Dept., 21, 1932: 44, fig.; also Bull. La. Conserv. Dept., 23, 1933: 43, fig. (relation., life hist.); Beebe and Tee-Van, Field Bk. Shore Fish. Bermuda, 1933: 34 (descr., distr., Bermuda); Gregory, Trans. Amer. philos. Soc., *23* (2), 1933: 144, fig. 37 (relations. as shown by skull); Breder, Zoologica, N. Y., *18*, 1934: 59 (Grassy Creek, Andros I., Bahamas); Beebe and Hollister, Zoologica, N. Y., *19* (6), 1935: 211 (leptocephali, adults, Union I., Grenadines, B. W. I.); Myers, Copeia, 1936: 83 (cf. *Dixonina nemoptera*); Hollister, Bull. N.Y. zool. Soc., *39*, 1936: 104–109, figs. (metamorphosis notes); Zoologica, N.Y., *21* (4), 1936: 268–275, figs. (caudal skel.); Farrington, Atlant. Game Fishing, 1937: 183–186 (scientific name not given, genl. acct., abund. Bimini, Bahamas); Fowler, Proc. Acad. nat. Sci. Philad., *89*, 1937: 304 (Ventnor, New Jersey); Heilner, Salt Water Fishing, 1937: 174–194 (genl. acct.); Kaplan, Big Game Angler's Paradise, 1937: 190–195 (genl. acct.); Butsch, J. Barbados Mus. nat. Hist. Soc., *7* (1), 1939: 18 (uncommon at Barbados); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 5 (color of leptocephali from Tortugas, Florida, described); Alexander, 'Dana' Rep., 53, 1961 (descr. larval develop.; world-wide distr. and hydrogr.).

Atopichthys esunculus Garman, Mem. Mus. comp. Zool. Harv., *24*, 1899: 327, pl. 65, figs. 2, 2a (orig. descr.; type local. off Acapulco, México; types in MCZ); Jordan, Evermann, and Clark, Rep. U.S. Comm. Fish. (1928), *2*, 1930: 54 (ref. to orig. descr.).

Elops saurus Gregg (not *Elops saurus* Linnaeus, but *Esox vulpes* Linnaeus), Where to Catch Fish. E. Cst. Fla., 1902: 33, fig. (descr., habitat, feed., instruct. for angling, fairly edible).

Negative Reference:

Albula vulpes Gregg, Where to Catch Fish. E. Cst. Fla., 1902: 34 (not *Albula vulpes* Linnaeus, but *Elops saurus* Linnaeus).

Genus *Dixonina* Fowler 1911

Dixonina Fowler, Proc. Acad. nat. Sci. Philad. (1910), 1911: 651; type species by original designation, *Dixonina nemoptera* Fowler.

Characters. See species account below.

Remarks. Dixonina is easily distinguished from *Albula* by the produced last ray of both dorsal and anal fins. Furthermore, *Dixonina* has a somewhat longer and more conical snout and a larger mouth than *Albula.*

Range. A single species is known; this has been reported from the West Indies, Venezuela, northern Brazil, and from the Pacific coast of México and Central America.

Dixonina nemoptera Fowler 1911

Shafted Bonefish[18]

Figure 24

Study Material. One Pacific coast specimen, about 413 mm long, 334 mm SL, from Acapulco, México, USNM 75547, recorded by Myers.

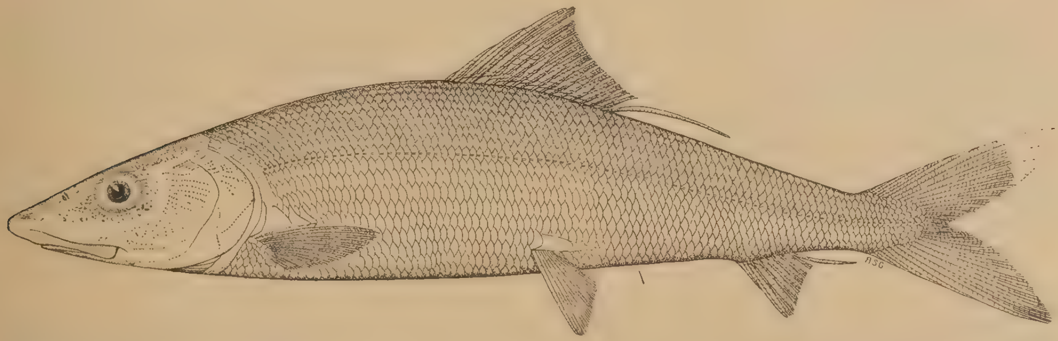

FIGURE 24. *Dixonina nemoptera,* 413 mm TL, Acapulco, Pacific coast of México, USNM 75547. From drawing by Ann S. Green.

Description. Proportional dimensions in per cent of standard length, and counts, based on Pacific specimen 334 mm SL.

Body: depth at origin of dorsal 23.
Head: length 29.5.
Snout: length 10.8.
Eye: diameter 5.4.
Maxillary: length from tip of snout 13.5.
Anal fin: length of base 5.5.
Pectoral fin: length 15.6.

Scales: 76.
Gill rakers: 5 + 10.
Fin rays: dorsal 19; anal 8; pectoral 16.

BODY slender, the back somewhat elevated, the ventral outline nearly straight; depth at origin of dorsal 4.3 in SL. SCALES firm, with crenulate membranous edges.

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[18] Name suggested by George S. Myers.

HEAD long and low, flat above, its depth at middle of eye exceeding its width at the same place by diameter of pupil, 3.4 in SL. SNOUT very long, projecting more than a third of its length beyond mandible, 2.7 in head. EYE moderately small, 5.4 in head, its center notably nearer to tip of snout than to margin of opercle. MAXILLARY extending nearly to middle of eye, 2.15 in head (measured from tip of snout).

DORSAL fin moderately high anteriorly, its longest anterior rays about as long as snout and eye, its last ray filamentous, almost reaching vertical from origin of anal, its origin about equidistant between tip of snout and caudal base. CAUDAL deeply forked, the upper lobe apparently longer than the lower (somewhat damaged). ANAL very small, its last ray produced, extending nearly to base of caudal fulcra, its origin equidistant between base of caudal and base of last dorsal ray, its base 3.5 in head. PELVIC not much smaller than pectoral, inserted about under middle of dorsal. PECTORAL not falcate, extending halfway to pelvic, 1.9 in head. AXILLARY SCALE of pectoral adherent to body, not very distinct.

Color. An old preserved specimen, slightly bluish above, silvery below; narrow dark streaks between rows of scales on upper part of side. Live specimens from the Pacific were described by Beebe (*4*: 44) as follows:

> Brilliant silver, appearing dark above in certain lights with dark green on the head; this dorsal pigmentation resolves into eight very dark lines along each side of upper half of the body, covering about one-fourth of each scale nearest to the adjoining line. Dorsal fin greenish, caudal dusky, anal silvery at base, a dusky spot at pectoral base, with yellow spot behind; basal membrane of pectoral apple green, rest of fin dusky. These colors fade at death. Iris silvery.
>
> In the young, at least up to 90 mm in length, two rows of dark spots extend along the side of body, the upper close to the mid-back. In a 115 mm fish the spots are less conspicuous and the dorsal dark lines begin to be distinct. The spots persist after death. In full-grown fish the dark scale lines are fainter than in fish of medium size.

Relationship. The specimen at hand from the Pacific agrees very well with two published accounts of Atlantic fish. Some Pacific coast specimens have been described as *D. pacifica* by Beebe (*4*: 43), who considered them specifically distinct from the Atlantic ones. On the basis of available descriptions (not specimens) of Atlantic fish, the differences between his Pacific specimens and those from the Atlantic were set forth as follows:

> In the former (*D. pacifica*) there is a greater number of lateral line scales (81 to 84, as compared with 76); increased number of vertical lines of scales on dorsal half (9 not 7) and on ventral half (9 not 7); decrease in predorsal scales (22 instead of 30); small eye (6.8 to 7, not 4.15); longer pelvic fins (2.2 and not 2.7); greater number of gill-rakers (7 + 11 instead of 4 + 9).

Most of the apparent distinctions between the Atlantic and Pacific specimens pointed out by Beebe become obscure or are of doubtful value in the light of measurements and enumerations based on the Acapulco fish. The number of scales in a longitudinal series seems to differ on the opposite sides of this fish; on the right side I counted 76 scales with pores (excluding greatly reduced ones on caudal base) and 79 on the left.

Again, I counted 77 oblique series (running upward and backward) just above the lateral line on the right side and 83 on the left. No variation in the number of longitudinal rows between the lateral line and origin of dorsal, and between the lateral line and origin of anal, occurs in the specimen studied, as these are respectively 8 and 6 full rows on each side. As to the number of scales in advance of the dorsal, the specimen before me has 21 modified scales in the median series, and 31 oblique series of ordinary scales (running upward and backward) on each side of the median row.

As neither Fowler (*24*: 652) nor Beebe stated which of the two was counted, I made inquiry of Mr. Fowler, who re-examined the type and found 21 modified scales in the median series, and 30–32 ordinary scales in the oblique series. As to the size of the eye in proportion to the length of the head, the specimen at hand is intermediate, the eye being contained in the head 5.4 times. The pelvic fin also is intermediate, its length 2.35 times in head. I have no doubt that the gill rakers in *Dixonina* become shorter and obscure with age, as they do in *Albula*, and that in large specimens it is difficult without dissection to see all of the bases, for that is all that remains of some of them. In the specimen from Acapulco, I find 5 + 10, including one in the angle with the lower limb count, a figure intermediate between counts given by Beebe and by Fowler.

It may be concluded, on the basis of the evidence presented, that *D. pacifica* for the present at least is a synonym of *D. nemoptera*.

Range. This albulid, as here understood, is known from the Atlantic from the type taken at Santo Domingo and from a specimen collected at Puerto Cabello, Venezuela.[19] For the Pacific it is known from a specimen taken at Acapulco, México (reported by Myers), and from 19 specimens taken off the coast of Costa Rica (reported as *D. pacifica* by Beebe). According to Walford (*71*: 119), the fish from the Gulf of California figured as *Albula vulpes* by Kumada and Hiyama (*47*: pl. 5) also is this species.

Synonyms and References:

Dixonina nemoptera Fowler, Proc. Acad. nat. Sci. Philad. (1910), 1911: 652, fig. (orig. descr.; type local. Santo Domingo, West Indies; ANSP 1597); Myers, Copeia, 1936: 83 (Acapulco, México; relation. to *Albula*); Walford, Copeia, 1939: 119 (specimen from Gulf of California, figured as *Albula vulpes* in *47*, is *Dixonina*).

Albula nemoptera Metzelaar, Trop. Atlant. Vissch., 1919: 9 (descr.; Puerto Cabello, Venezuela).

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[19] One seen from Brazil.—G. S. Myers.

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Printed in Denmark for the Sears Foundation for Marine Research, Yale University, New Haven, Connecticut, USA.
Bianco Luno's Printing, Copenhagen, Denmark

Reprinted from Memoir Sears Foundation for Marine Research, I (3), 1963: 152–249

Family Engraulidae[1]

SAMUEL F. HILDEBRAND[2]

Characters. BODY moderately slender, compressed. CHEST and ABDOMEN in American species often carinate, without bony serrae. MOUTH horizontal or nearly so. MAXILLARY extending well beyond eye, sometimes nearly or quite to gill opening. SNOUT blunt, generally projecting far beyond tip of mandible. EYE placed well forward, in anterior half of head, sometimes with well developed adipose tissue in adults. PREMAXILLARIES not protractile, embedded in tissue of snout anteriorly, widely separated medianly. TEETH typically minute (some on jaw enlarged in *Lycengraulis*); present on jaws, vomer, palatines, pterygoids, and hyoids. GILL COVERS generally separate and free from isthmus (connected by a thin membrane in *Cetengraulis*). PSEUDOBRANCHIAE present. GILL RAKERS generally slender, rarely short, broad, and spiny; increasing in number with age in some species (as in *Anchovia*). SCALES thin, cycloid (usually lost on preserved specimens), generally if not always forming a sheath on bases of dorsal and anal fins; an enlarged scale in axil of pectoral and pelvic fins in American species. LATERAL LINE absent. DORSAL fin usually median in position, rarely behind mid-length, with about 12–16 rays in American genera. ADIPOSE FIN lacking. CAUDAL FIN rather deeply forked. ANAL with various ray counts, about 15–40 in American species.

Genera. The division of the family into compact and clearly definable genera is difficult. Thus there is a divergence of opinion among students concerning the status of described genera. Seven genera have been recognized (*3*), all confined to American waters, excepting *Engraulis*, which, though not represented in the western North Atlantic, is very widely distributed in both hemispheres; 75 species have been recognized, 44 from the Atlantic and 32 from the Pacific, including one species common to both coasts of tropical America. For the Atlantic species that come within the scope of this work, see the Table of Contents.

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[1] Edited, with some revision and expansion, by George S. Myers, Myvanwy M. Dick, Henry B. Bigelow, and Yngve H. Olsen.

[2] August 15, 1883–March 16, 1949.

Commercial Importance. Some anchovies, because of their tremendous abundance, are of considerable importance. Some are canned whole or are used in the production of anchovy paste, and larger species are commonly sold fresh in the market, as in South America; they are also used extensively as bait. But their value as a forage fish for water birds and creatures that frequent the sea far exceeds their direct value to man. Many of the larger commercially important fishes, such as the seatrout, bluefish, and mackerels, feed on them extensively.

Range. Representatives of the family occur in the warmer shore waters throughout the world. Some of the species ascend freshwater streams, and probably a few live entirely in fresh water. The Engraulidae are most numerous in tropical regions, but several species either range into temperate waters or live there permanently.

Key to Genera of the Western North Atlantic

1a. Gill covers not connected across isthmus by a membrane.
  2a. Teeth in jaws small or minute, all of about uniform size.
    3a. Origin of anal fin posterior to origin of dorsal; tip of pelvic fin usually below origin of dorsal.
      4a. Maxillary more or less sharply pointed distally, generally reaching well beyond joint of mandible, often to margin of opercle, or nearly so.
        5a. Gill rakers close-set, increasing in number with age, 40–50 in young, about 130 in adults, on lower limb of first arch; body depth usually more than 25% of length; maximum size about 250 mm. *Anchovia* Jordan and Evermann 1896, p. 155.
        5b. Gill rakers not close-set, only about 15–30 on lower limb, not known to increase in number with age; body depth usually less than 25% of length; maximum size generally under 150 mm. *Anchoa* Jordan and Evermann 1927, p. 162.
      4b. Maxillary square or rounded distally, rarely reaching joint of mandible. *Anchoviella* Fowler 1911, p. 204.
    3b. Origin of anal fin in advance of dorsal origin, rarely under it; tip of pelvic fin anterior to a vertical from dorsal origin by a distance equal to about 50% of head.
      6a. Distance of dorsal fin origin from tip of snout much less than twice the distance from dorsal origin to caudal base; gill rakers short and broad, only about 14 on lower limb of first arch; anal with 30–33 rays. *Pterengraulis* Günther 1868, p. 228.

6b. Distance of dorsal origin from tip of snout about twice the distance of dorsal origin from caudal base; gill rakers long, slender, about 33 on lower limb of first arch in young, probably more in adults; anal with about 25 rays. *Hildebrandichthys* Schultz 1949, p. 230.

2b. Teeth in jaws, especially the lower ones, notably large, usually unequal in size. *Lycengraulis* Günther 1868, p. 233.

1b. Gill covers broadly connected across isthmus by a thin membrane (easily torn). *Cetengraulis* Günther 1868, p. 245.

Explanation of Measurements and Counts for Engraulidae.

Total length: from tip of snout to vertical at rearmost point of longest caudal lobe.

Standard length: from tip of snout to base of caudal fin, i.e. to the last vertebra, as nearly as can be determined without dissection.

Caudal peduncle: least depth unless otherwise noted.

Length of head: from tip of snout to most distal part of bony opercular margin, regardless of whether the straight line between these points is horizontal or oblique.

Depth of head: vertical distance at joint of mandible.

Postorbital length: from posterior rim of eye to most distal part of bony opercular margin.

Maxillary: from its anterior embedded end (located by touch) to its posterior extremity.

Cheek (smooth bone below and behind eye): distance from rim of eye to its distal point; the degree of its posterior angle determined by a protractor.

Dorsal and Anal fins: the counts include all rays, whether simple and unsegmented, simple and segmented, or branched; the last ray of the anal, even though split to the base, was counted as one unless definitely separated at base.

Length of pectoral: from base of upper ray to tip of longest ray.

Pectoral axillary scale: distance from base of upper ray of pectoral to tip of the modified scale or process.

Splint: adhering to first ray of pectoral; not considered distinct and not counted.

Scales or Scale pockets: counted along the side from the upper anterior angle of the gill opening to the base of the caudal; as the scales are nearly always lost in preserved specimens, they are generally not shown in the illustrations, except for a small patch.

Gill rakers: the counts are given as a formula, e.g. 12–16 + 15–18 (as for *Anchoa spinifer*), meaning a range of 12–16 rakers on the upper limb of the first branchial arch and 15–18 on the lower limb. The counts include those rudiments, if present, that have a free tip but not those that are mere tubercles. The gill raker at the angle of the first arch generally has a plainly visible root, extending either upward or downward; if the root was directed upward, the raker was included with the upper limb count; if directed downward, it was counted with the lower limb count. Rarely, the raker at the angle has two roots, one directed upward and one downward; in such cases it was included with the lower limb count.

VERTEBRAE: total number, including hypural, as determined by dissections.

Genus *Anchovia* Jordan and Evermann 1896

Anchovia Jordan and Evermann, Bull. U. S. nat. Mus., *47* (1), 1896: 449; type species by original designation, *Engraulis macrolepidotus* Kner and Steindachner 1864.

Characters. BODY in adults compressed, its depth about 2.6–3.8 in SL. SCALES firm, rather adherent. TEETH small, not disappearing with age. GILL RAKERS numerous, increasing in number with age, about 40 on lower limb in young, 100 or more in large specimens. ANAL origin somewhere under anterior 66% of dorsal base. VERTEBRAE 41–43.

Size. A length of 175 mm and upward is attained by most of the species.

Species. The genus *Anchovia* is represented in the Atlantic by *A. clupeoides* and *A. nigra*, and in the Pacific by three species.

Range. In the Atlantic, from the West Indies southward to or beyond Pernambuco (Recife), Brazil, and in the Pacific from the Gulf of California to Ecuador.

Key to Species of the Western Atlantic

1a. Insertion of pelvic fins about equidistant between base of upper ray of pectoral fin and origin of anal; snout projecting beyond mandible by about half its length; anal fin with 30–35 rays, most frequently with 33; vertebrae 42 or 43.
clupeoides (Swainson) 1839, below.

1b. Insertion of pelvic fins nearer to base of upper rays of pectoral fin than to origin of anal; snout projecting beyond mandible by about 67% of its length; anal fin with 28–32 rays, most frequently with 29–31; vertebrae 39–41.
nigra Schultz 1949, p. 158.

Anchovia clupeoides (Swainson) 1839

Sardina Boca Torta, Bocón, Hachudo

Figure 25

Study Material. At least 29 specimens, 75–205 mm TL, from: Puerto Rico; Jamaica; Cuba; Trinidad; several places on the Atlantic coast of Panama; the Gulf of Venezuela; Laguna de Tacarigua, Venezuela; and Pará, Rio Grande do Norte, and Pernambuco (Recife), Brazil. Some small specimens, 48 mm TL and upward, are at hand, but their proportions are not included because they differ considerably from the larger ones, especially in having a more slender body.

Distinctive Characters. A. clupeoides is closely related to *A. rastralis* of the Pacific coast of Middle America, from which it differs in having a slightly longer anal fin, inserted a little farther forward with respect to the dorsal. In specimens of equal size, the maxillary is usually a little shorter and tapers more abruptly in *clupeoides*, and its body is somewhat more slender. *A. clupeoides* apparently grows to a larger size than *A. rastralis*, for none of the latter has been reported to be larger than 110 mm TL. See also *A. nigra*, p. 161.

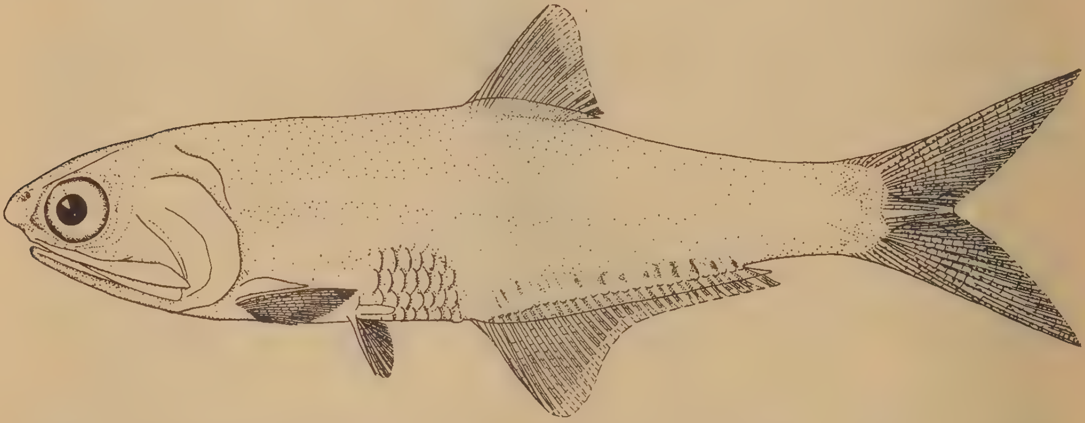

FIGURE 25. *Anchovia clupeoides*, 60 mm TL, 44 mm SL, from Gulf of Venezuela, USNM 127552. Drawn by Louella E. Cable.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens 75–205 mm TL.

Body: depth 25–31.
Head: length 27.6–31.
Snout: length 3.1–4.3.
Eye: diameter 6.0–8.3.
Postorbital: distance 15.5–18.5.
Maxillary: length 19.5–22.
Mandible: length 19–20.5.
Anal fin: length of base 30–33.
Pectoral fin: length 15.4–17.3.
Scales: *ca.* 39–43.
Gill rakers: *ca.* 35–40 in younger specimens, 75–110 in those of 130 mm TL.
Fin rays: dorsal 13–15; anal 30–35; pectoral 13 or 14.
Vertebrae: 42 or 43 (6 specimens).

BODY strongly compressed, its depth increasing with age, about 3.2–4.0 in SL in specimens 75 mm TL and upward (*ca.* 4.5 at 50 mm). HEAD 3.2–3.6 in SL, its depth about equal to its length without snout in specimens 150–160 mm TL; less in smaller ones. SNOUT short, projecting about half of its length beyond mandible, 6.0–8.0 in head. EYE 3.5–4.5 in head. MAXILLARY abruptly pointed, reaching to or beyond joint of mandible, 1.3–1.5 in head. MANDIBLE 1.4–1.6 in head. CHEEK as long as snout and eye in large ones, proportionately shorter in small ones, its posterior angle about 35°. GILL RAKERS at angle fully as long as eye in large specimens, shorter in young.

DORSAL fin originating equidistant between caudal base and anterior half of eye, its longest rays often reaching beyond tip of last ray if deflexed. ANAL originating about under middle of dorsal base, its base 3.0–3.5 in SL. PELVIC small, reaching only a little more than halfway to origin of anal, inserted about equidistant between base of pectoral and origin of anal. PECTORAL fin reaching to or slightly beyond base of pelvic in small specimens, often not quite to pelvic in large examples, 1.7–1.9 in head. AXILLARY SCALE of pectoral broad, about half as long as fin, 3.0–3.9 in head.

Color. In alcohol, pale; side of head and lower 75% of body silvery. Young with a silvery lateral band, becoming diffuse in specimens about 100 mm long and disappearing entirely with age. Middle of back with dark streak (missing in some, probably due to fading). Fins unmarked.

Size. The largest specimen examined is 170 mm TL, but 300 mm has been reported (7: 413).

Relation to Man. Its commercial importance is not significant. It occurs occasionally in the Colón market (Panama) and, according to report, in the Havana market (Cuba).

Range. Its range extends from the West Indies to Panama and at least as far southward as Pernambuco (Recife), Brazil, probably to Rio de Janeiro and São Paulo. All specimens studied were apparently taken in salt or brackish water, with one exception; one specimen (CAS 9398) from Lake Rogagua, Bolivia, seems to be this species.

Synonyms and References:

Engraulis clupeoides Swainson, Nat. Hist. Fish. Amphib. Rept., *2*, 1839: 388 (orig. descr.; type local. Pernambuco, Brazil).

Engraulis productus Poey, Repert. Fisico-Nat. Cuba, *1*, 1866: 380 (orig. descr.; type local. Matanzas, Cuba; type MCZ 17961); Poey, Repert. Fisico-Nat. Cuba, *2*, 1868: 423 (Havana, Cuba); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 388 (descr., Cuba and Jamaica); Tortonese, Bull. Mus. Zool. Anat. comp. Torino, (3) *47*, 1929: 6 (diagn., Puerto Cabello, Venezuela).

Engraulis surinamensis Steindachner (not of Bleeker), Ichthyol. Beitr., *8*, 1879: 55 (descr., Bahia, Brazil).

Stolephorus clupeoides Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 447 (descr., range, *S. surinamensis* probably incorrectly put in synon.; see *Cetengraulis edentulus*, p. 245); Eigenmann, Rep. Princeton Exped. Patagonia, 1896–1899, *3* (4), 1910; 45 (Surinam to Rio Grande do Sul; *S. surinamensis* Bleeker apparently incorrectly put in synon.).

Stolephorus productus Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 447 (descr., Cuba and Jamaica); Jordan and Rutter, Proc. Acad. nat. Sci. Philad., 1897: 96 (descr., Jamaica); Evermann and Marsh, Bull. U. S. Fish Comm., *20* (1), 1900: 90 (descr., Palo Seco, and Ponce, Puerto Rico); Nichols, Bull. Amer. Mus. nat. Hist., *31*, 1912: 182 ("Havana market").

Anchovia clupeoides Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 211 (Santo Domingo and Rio Seco, Puerto Rico; *E. productus* Poey put in synon.); Starks, Stanf. Univ. Publ. Biol., 1913: 9 (notes, Lake Papary, Natal, Brazil); Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 412 (descr., range, synon., partly incorrect); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 50 (range, synon., partly incorrect); Fowler, Proc. Acad. nat. Sci. Philad., *83*, 1931: 393 (diagn., Quaima R., Trinidad); Howell-Rivero, Bull. Mus. comp. Zool. Harv., *82*, 1938: 172 (synon.; the larger of two specimens

[MCZ 17961, Poey's 36] stated to be holotype); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 27, fig. 9 (descr., range, synon.); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 39 (synon., locals. listed).

Anchovia producta Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 210 (descr., Mindi Cut, Colón [market], and Porto Bello, Panama); Nichols, Ann. N. Y. Acad. Sci., *10* (2), 1929: 206 (diagn., range, "not uncommon about Puerto Rico").

Anchovia macrolepidota Fowler (not of Kner and Steindachner), Proc. Acad. nat. Sci. Philad., 1917: 130 (two from Colón, Panama, found by present writer to be *A. clupeoides*).

Anchoviella clupeoides Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (Brazilian rec.).

Doubtful References:

Stolephorus productus Schreiner and Ribeiro, Arch. Mus. nac., Rio de J., *12*, 1903: 93 (Rio de Janeiro, without comment).

Stolephorus clupeoides Eigenmann and Norris, Rev. Mus. paul., *4*, 1904: 360 (one from São Paulo, Brazil; proportions given indicate ident. probably not correct).

Anchovia nigra Schultz 1949[3]

La anchoa

Figure 26

Study Material. Many paratypes, 14–76 mm TL (12–60 mm SL), and the type, 125 mm TL (95 mm SL), from Lake Maracaibo and its tributary streams.

Distinctive Characters. See *Relationship and Variation*, p. 161.

Description. Proportional dimensions in per cent of standard length, not including small examples regarded as juveniles because they would distort the picture; dimensions and counts based on 11 or more specimens from *Study Material*, 50 mm TL and over.

Body: depth 21–28.9.
Head: length 23–31.3.
Snout: length 4.15–4.3.
Eye: diameter 6.1–8.3.
Postorbital: distance 15–19.
Maxillary: length 18.5–24.
Mandible: length 17–22.
Anal fin: length of base 26–31.
Pectoral fin: length 16–18.

Scales: *ca.* 40–48.
Gill rakers: *ca.* 70+140 in adults, fewer in young.
Fin rays: dorsal 12–14; anal 29–31; pectoral 12 or 13.
Vertebrae: 39–41 (18 specimens).

Body strongly compressed, rather deep, its depth increasing with age, 3.5–4.75 in SL in specimens 60–125 mm TL, about 5.5 in specimens around 25 mm. Head 3.2–4.35, its depth scarcely as great as length of head without snout. Snout short, projecting 66% of its length beyond mandible, 6.5–7.1 in head. Eye 3.7–4.3. Postorbital length 5.25–6.7. Maxillary abruptly pointed, reaching to or a little beyond joint of mandible, 1.25–1.4 in head. Mandible 1.4–1.5. Cheek moderately long and narrow, about equal to length of snout and eye in adults, its posterior angle approximately 30°. GILL RAKERS at angle fully as long as eye in adults, proportionately shorter in young.

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[3] Dr. Leonard P. Schultz has kindly placed his data on this species in my hands. The proportions and counts used in the *Description* are his and mine.

DORSAL fin moderately high anteriorly, the longest rays reaching to or beyond tip of last ray if deflexed, its origin somewhat variable, generally a little nearer to base of caudal than the tip of snout. ANAL fin moderately long, its origin somewhat variable, sometimes nearly under middle of dorsal base, more frequently anterior to this point, its base generally about equal to length of head, 3.2–3.85 in SL. PELVIC fin small, reaching a little more than halfway to origin of anal, inserted a little nearer to base of pectoral than to origin of anal. PECTORAL fin rather large, reaching well beyond base of pelvic, 1.6–1.9 in head. AXILLARY SCALE of pectoral fin broad at base, variable in length, usually reaching to middle of fin or beyond, 3.4–4.1 in head.

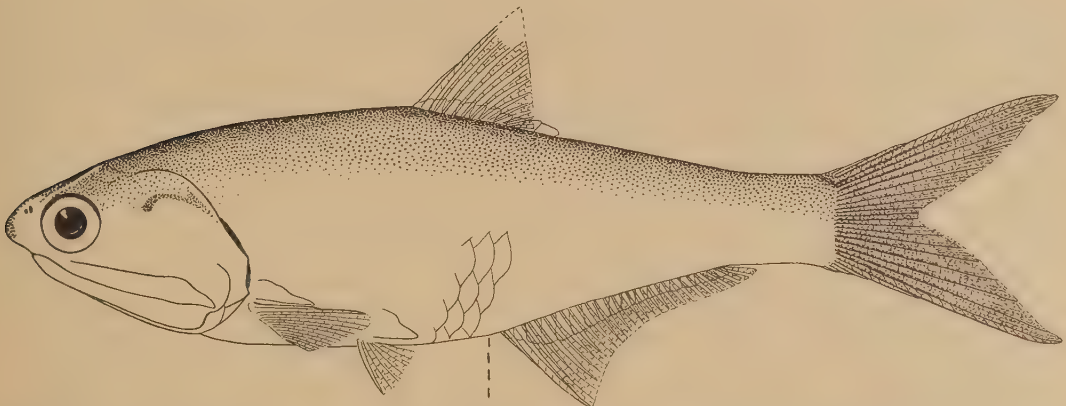

FIGURE 26. *Anchovia nigra*, type specimen, 125 mm TL, from Maracaibo Basin, Venezuela, USNM 121761. Drawn by A. M. Awl.

Color. In alcohol, back a pale straw color. Sides silvery. Silvery lateral band in specimens up to 75 mm TL, the band very narrow in 40-mm specimens, becoming proportionately broader and less well defined ventrally, diffused with silvery color on lower part of sides in largest example; dark streak present on middle of back in large examples but scarcely evident in small ones in which the dark punctulations that later form the band remain separate; scattered punctulations extending down to silvery lateral band. Dorsal and caudal fins with dark points; other fins plain translucent; small specimens, 75 mm TL and under, with dark dots along base of anal fin and on ventral surface of caudal peduncle.

Size. The largest specimen examined, the type (USNM 121761), is 125 mm (5 in.) TL or 95 mm SL. Since a length of 300 mm (12 in.) has been reported for its near relative, *clupeoides*, it may be assumed that larger examples of *nigra* will be found.

Development. The smallest specimen, only 14 mm, is very slender, its depth 9.15 and the head 4.0 times in SL. In this specimen the mouth is nearly terminal, the lower jaw is very thin, the gape ends under the eye, and the maxillary is imperfectly developed. The convoluted intestine, which is usual in larval herring and herring-like fishes, is externally visible. All fins, however, are sufficiently developed to have at least rudimentary rays. The body is pale, no doubt transparent in life, as general pigmentation has not taken place. The juvenile markings consist of dark dots, which, exclusive of a few spots at the nape, are on the lower part of the body; and a few less definite ones are on the side of the head. An elongate median streak extends backward from the isthmus; also there are spots along each side of the ventral edge of the abdomen that become darker and more concentrated along the base of the anal and are reduced to a single row on the midventral line of the caudal peduncle. A row of indefinite dark dots extends along the lateral side of the tail from above the anal base to the caudal base; there are a few more dark dots on the caudal fin.

The body of a fish 20 mm TL is proportionately much deeper than the 14-mm example, as its depth is contained 5.5 times in SL. The proportion of the head does not differ greatly from either the small or large ones described, being 3.75 in SL. Much progress in the development of the mouth parts has been made, however, for the snout is more pointed and it projects prominently beyond the lower jaw. The maxillary is definitely visible and extends well beyond the posterior margin of the eye, where it ends in a rather blunt point. The intestine is no longer visible externally. Pigmentation on the lower part of the body remains about the same as in the smaller example, but dorsally, especially on the median line of the back and on the head, the dark dots are more numerous.

The advances in development with growth between 20–30 mm are not great. The increase in proportionate depth has continued, with the depth now 5.0 times in SL. The snout has become more pointed and projects somewhat more strongly, about as in adults. Some of the gill rakers are developed, 10+20 having been counted in one specimen. Pigmentation has advanced somewhat, as dark dots on the back and on the head have become larger and more numerous. The dark line behind the isthmus has virtually disappeared. The dark spots on the side of the abdomen, along the base of the anal, and on the ventral side of the caudal peduncle have become less distinct. A few elongate dark markings at the base of the outer rays of both lobes of the caudal, already present in the 20-mm specimen, have become more distinct.

In a fish 40 mm long, the depth is contained 4.5 times in SL, and the head 3.5 times. The cheek and opercular bones are well outlined. And the maxillary, which now reaches the margin of the opercle, is provided with minute teeth along its free margin. The gill rakers on the first arch are so numerous and close-set that they are difficult to count; about 35–45 seem to be present. Pigmentation continues to advance; the dark dots on the back have become more numerous and those on the lower parts, exclusive of the ones along the anal base and on the peduncle behind the anal, have disappeared. The upper parts of the body are slightly straw-colored and the sides of the head are bright silvery; the lower part of the body shows a somewhat silvery sheen, and there is slight evidence of a silvery lateral band on the anterior half of the body.

A specimen 70 mm long is shaped essentially like the type, which is 125 mm TL; the body is proportionately about as deep in a 70-mm specimen as in the type; however, the gill rakers on the first arch are fewer, as 44 + 70 were counted, whereas about 70 + 140 seem to be present in the type. Furthermore, the smaller specimen retains the silvery lateral band which the larger specimen has lost; it also retains the juvenile dark markings along the base of the anal fin, which are missing in the larger one.

Relationship and Variation. This species is very close to *clupeoides*, from which it differs significantly in the number of vertebrae, the range in 17 specimens of *nigra* being 39–41 and in 22 specimens of *clupeoides* 42 or 43. The anal fin may begin under the middle of the dorsal base or well in advance of that point in *nigra*, consequently it overlaps with *clupeoides*, in which this fin begins about under the beginning of the second third of the dorsal base. Furthermore, *nigra* generally has fewer rays in the anal fin than *clupeoides*, 28–32 (av. around 30) in 38 specimens, and 30–35 (av. 33) in 58 specimens of *clupeoides*. The lower average number of rays in the anal of *nigra* is reflected in its somewhat shorter base, 3.2–3.85 in SL in 38 specimens of *nigra*, but 3.0–3.5 in 32 specimens of *clupeoides*. The pectoral fin of *nigra* extends well beyond the base of the pelvic fin in smaller specimens and only slightly beyond this point in the largest example, being variable with age in this respect; in *clupeoides* the pectoral generally does not extend quite so far back as the pelvic fin; nevertheless, enough overlapping occurs so that the character is not diagnostic. However, the place of insertion of the pelvic fin generally is diagnostic; in *nigra* it is nearly always inserted somewhat nearer to the base of the upper pectoral rays than to the origin of the anal, whereas in *clupeoides* its insertion generally is almost exactly equidistant between the two points mentioned. Finally, the snout projects about 66 % of its length beyond the mandible in *nigra*, and only about half of its length beyond the mandible in *clupeoides*.

A. nigra is also closely related to *A. rastralis* of the Pacific coast of tropical America. But in *nigra* the pelvic fins are inserted somewhat nearer to the pectoral base than to the anal origin, whereas in *rastralis* they are inserted notably nearer to the anal origin than to the pectoral base. The anal in *nigra* begins at, or more usually in advance of, the vertical from the middle of the dorsal base, whereas in *rastralis* it generally begins at or behind this point; and *nigra* has 39–41 vertebrae, whereas *rostralis* (like *clupeoides*) has 42 or 43.

Habitat and Range. A. nigra is known only from the fresh or slightly brackish water of Lake Maracaibo, Venezuela, and from the lower sections of its tributary streams. Apparently it does not enter the salt water of the Gulf of Venezuela, where *clupeoides* has been taken.

Reference:

Anchovia nigra Schultz, Proc. U. S. nat. Mus., *99*, 1949: 39, fig. 4 (orig. descr.; type local. Lake Maracaibo, Venezuela; type USNM 121761).

Genus *Anchoa* Jordan and Evermann 1927

Anchoa Jordan and Evermann, Proc. Calif. Acad. Sci., *4* (16), 1927: 501; type species by original designation, *Engraulis compressus* Girard 1858.

Characters. BODY usually quite elongate, moderately to strongly compressed. MAXILLARY long, reaching to, or more usually beyond, joint of mandible, frequently to or nearly to margin of opercle, always more or less pointed (except in very young). GILL RAKERS not numerous, seldom more than 22 on upper limb or more than 28 on lower limb except in *cubana* among Atlantic species, not increasing in number with age and growth. ANAL origin under base of dorsal, rarely wholly behind it. VERTEBRAE 38–44, rarely 45 (in Atlantic species).

Remarks. This genus differs from *Anchoviella* principally in its longer maxillary, which is somewhat sharply pointed rather than rounded or squared distally. From *Anchovia* it differs in the fewer gill rakers, the number of which does not increase with age. It differs principally from *Engraulis* (not represented in the western North Atlantic) in the more compressed body (also frequently deeper), and usually in the fewer vertebrae.

Species and Range. This genus contains many species that range the Atlantic from Massachusetts (rarely Nova Scotia) to Argentina, and the Pacific from California to Peru. Some of the species enter brackish or almost fresh water, but none is known to run far upstream.

Table I. Frequency Distribution of Anal Rays in *Anchoa*.

	Number of Rays																						
	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
spinifer	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	3	13	6	2	2
argenteus	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—
duodecim	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—
trinitatis	—	—	—	—	—	—	—	—	2	4	7	5	2	—	—	—	—	—	—	—	—	—	—
cayorum	—	—	—	—	—	—	—	3	22	22	12	4	—	—	—	—	—	—	—	—	—	—	—
pectoralis	—	—	—	—	—	—	—	6	8	2	1	—	—	—	—	—	—	—	—	—	—	—	—
mitchilli mitchilli	—	—	—	—	—	1	8	22	63	74	51	30	11	1	—	—	—	—	—	—	—	—	—
mitchilli diaphana	—	—	—	—	—	2	11	55	83	62	44	14	5	—	—	—	—	—	—	—	—	—	—
parva	—	—	1	8	18	18	3	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
januaria	—	—	—	1	3	12	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
choerostoma	—	—	—	5	14	16	9	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
tricolor	2	9	30	17	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
cubana	—	—	9	13	7	9	4	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
ginsburgi	3	3	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
lamprotaenia	—	1	10	31	43	81	56	14	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—
hepsetus hepsetus	21	28	42	57	20	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
hepsetus colonensis	3	4	13	13	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
lyolepis	—	2	7	11	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
filifera	—	1	3	3	5	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Key to Species of the Western North Atlantic

1a. Anal fin with 25 rays or more (*m. mitchilli* rarely with 24); anal base 25–35.6% of SL (*pectoralis* sometimes only 23.4%).

  2a. Origin of dorsal about an eye's diameter nearer to tip of snout than to base of caudal; anal with 30 rays or more.

    3a. Origin of anal under or somewhat in advance of middle of dorsal base; 32 or more anal rays.

      4a. Anal with 35–40 rays; pectoral fin generally reaching far beyond base of pelvic fin, 5.0–5.7 in SL; margin of caudal black.
      spinifer (Cuvier and Valenciennes) 1848, p. 167.

      4b. Anal with 32 rays; pectoral fin not reaching far beyond base of pelvic fin, 6.5 in SL; margin of caudal not black.
      argenteus Schultz 1949, p. 169.

    3b. Origin of anal behind dorsal base; 30 anal rays.
    duodecim (Cope) 1869, p. 170.

  2b. Origin of dorsal nearer to base of caudal than to tip of snout; anal usually with less than 30 rays (*mitchilli* and *trinitatis* sometimes with as many as 30).

    5a. Origin of dorsal nearer to posterior margin of eye than to base of caudal; longest rays of dorsal reaching to or beyond tip of last ray when deflexed; pectoral usually with more than 12 rays (*cayorum* sometimes with only 12).

      6a. Depth of body 22.2–25.5% of SL; gill rakers usually 16–19 + 19–22 (rarely only 15 on upper limb); anal base 29.4–33.4% of SL.
      trinitatis (Fowler) 1915, p. 171.

      6b. Depth of body 18.2–22.2% of SL; gill rakers 12–14 + 17–19 (*cayorum* rarely with 15 on upper limb, *pectoralis* occasionally with 20 on lower limb); anal base 23.5–29.4% of SL.

        7a. Maxillary narrowly pointed, extending nearly or quite to margin of opercle, 19.2–22.5% of SL; origin of anal well in advance of middle of dorsal base; pectoral with 12 or 13 rays, generally failing to reach base of pelvic fin by about half of diameter of eye, 13.9–16.6% of SL. *cayorum* (Fowler) 1906, p. 173.

        7b. Maxillary bluntly pointed, extending only slightly beyond joint of mandible, 17.7–19.0% of SL; origin of anal generally under middle of dorsal base; pectoral with 15–17 rays, reaching nearly to base of pelvic fin, 17.8–18.8% of SL.
        pectoralis Hildebrand 1943, p. 174.

    5b. Origin of dorsal nearer to base of caudal than to posterior margin of eye, very rarely equidistant; longest rays of dorsal usually failing to reach tip of last ray when deflexed; pectoral with 11 or 12 rays.
    mitchilli (Cuvier and Valenciennes) 1848, p. 176.

8a. Greatest thickness of body usually exceeding depth of caudal peduncle; depth 15.8–25% of SL; pectoral often failing to reach base of pelvic by diameter of eye, 12–18% of SL; vertebrae 39–44, most frequently 42. *m. mitchilli* Hildebrand 1943, p. 176.

8b. Greatest thickness of body often less than depth of caudal peduncle; depth 18.2–26.5% of SL; pectoral often extending to or nearly to base of pelvic, 13–20% of SL; vertebrae 38–42, most frequently 40. *m. diaphana* Hildebrand 1943, p. 176.

1b. Anal fin with less than 25 rays (*lamprotaenia* occasionally with 25 or 26 rays, *choerostoma* rarely with 25); anal base 17.2–25% of SL (*januaria* sometimes 26).

9a. Pectoral without a long, filamentous ray (rarely with a slight filament in *lamprotaenia*); origin of dorsal fin usually nearer to base of caudal than to tip of snout, rarely equidistant.

10a. Origin of anal in advance of base of last dorsal ray; depth of head at joint of mandible exceeding postorbital length; snout much shorter than eye; cheek shorter than snout and eye combined; silvery lateral band much narrower than eye.

11a. Gill rakers on lower limb 23–33, on upper limb 18–23 (rarely only 17).

12a. Depth of body 18.2–22% of SL; pectoral fin 14–18.5% of SL; gill rakers rather robust, not closely crowded, not difficult to count.

13a. Origin of anal under or near middle of dorsal base; depth of body 20–22% of SL.

14a. Maxillary sharply pointed distally, extending nearly to margin of opercle, 1.2–1.35 in head; vertebrae 38–40 (rarely 41). *parva* (Meek and Hildebrand) 1923, p. 181.

14b. Maxillary bluntly pointed distally, extending only to or slightly beyond joint of mandible, 1.3–1.5 in head; vertebrae 41 or 42. *januaria* (Steindachner) 1879, p. 183.

13b. Origin of anal far behind middle of dorsal base; depth of body 18.2–21% of SL.

15a. Cheek as long as eye and fully 75% of snout length; pectoral fin 15.6–18.5% of SL; axillary scale of pectoral about half of length of fin, 3.0–4.0 in head; anal with 22–24 rays. *choerostoma* (Goode) 1874, p. 185.

15b. Cheek scarcely longer than eye; pectoral fin 14–14.8% of SL; axillary scale of pectoral fully 75% of length of fin, 1.9–2.75 in head; anal with 18–22 rays. *tricolor* (Agassiz) 1829, p. 186.

12b. Depth of body 15–18% of SL; pectoral fin 12.5–13.7% of SL; gill rakers very slender, close-set, often difficult to count. *cubana* (Poey) 1868, p. 188.

11b. Gill rakers on lower limb usually 16–22 (rarely 23 in *h. hepsetus*), on upper limb usually 14–20 (rarely 13 or 21).

16a. Depth of body 17.4–18.8% of SL; maxillary bluntly pointed distally, its upper margin rounded, extending to joint of mandible, 17.2–18.2% of SL; vertebrae 44 or 45. *ginsburgi* Hildebrand 1943, p. 190.

16b. Depth of body 18.5–23% of SL; maxillary usually sharply pointed distally, generally extending beyond joint of mandible, sometimes to or nearly to margin of opercle (moderately short, rather blunt distally, and rounded above in *lamprotaenia*), 19–24.5% of SL; vertebrae 39–43 (*h. hepsetus* sometimes with 44).

17a. Longest rays of dorsal fin usually reaching well beyond tip of last ray when deflexed; origin of anal about under beginning of posterior third of dorsal base; axillary scale of pectoral only a little more than half of length of fin, 3.0–3.6 in head; cheek fully as long as eye and half of snout. *lamprotaenia* Hildebrand 1943, p. 192.

17b. Longest rays of dorsal fin failing to reach tip of last ray when deflexed; origin of anal usually about under middle of dorsal base, sometimes posterior to middle; axillary scale of pectoral 2.0–2.5 in head; cheek usually not much longer than eye. *hepsetus* (Linnaeus) 1758, p. 194.

18a. Pectoral fin often failing to reach base of pelvic by diameter of eye; silvery lateral band usually 75% of width of eye. *h. hepsetus* Hildebrand 1943, p. 194.

18b. Pectoral fin frequently extending to or nearly to base of pelvic; silvery lateral band often scarcely wider than pupil. *h. colonensis* Hildebrand 1943, p. 194.

10b. Origin of anal under or behind base of last dorsal ray; depth of head at joint of mandible equal to postorbital length; snout scarcely shorter than eye, 4.3–5.5 in head; cheek about as long as snout and eye combined; silvery lateral band as broad as eye. *lyolepis* (Evermann and Marsh) 1902, p. 200.

9b. Pectoral with a long filamentous ray; origin of dorsal fin usually nearer to tip of snout than to base of caudal. *filifera* (Fowler) 1915, p. 202.

Table II. Frequency Distribution of Gill Rakers on Upper Limb of First Arch in *Anchoa*.*

	Number of Gill Rakers											
	12	13	14	15	16	17	18	19	20	21	22	23
spinifer	1	2	11	14	3	—	—	—	—	—	—	—
argenteus	—	—	—	1	—	—	—	—	—	—	—	—
duodecim	—	—	1	1	—	—	—	—	—	—	—	—
trinitatis	—	—	—	1	1	7	9	1	—	—	—	—
cayorum	1	12	24	3	—	—	—	—	—	—	—	—
pectoralis	1	12	2	—	—	—	—	—	—	—	—	—
mitchilli mitchilli	—	—	—	8	38	63	56	5	—	—	—	—
mitchilli diaphana	—	—	—	9	95	118	44	8	—	—	—	—
parva	—	—	—	—	—	—	3	25	10	—	—	—
januaria	—	—	—	—	—	—	—	—	2	1	2	2
choerostoma	—	—	—	—	—	1	9	9	4	—	—	—
tricolor	—	—	—	—	—	—	1	7	19	8	1	—
cubana	—	—	—	—	—	2	3	9	12	5	8	5
ginsburgi	—	—	—	—	1	2	1	—	—	—	—	—
lamprotaenia	—	7	56	47	13	6	4	—	—	—	—	—
hepsetus hepsetus	—	—	—	1	19	52	47	23	9	—	—	—
hepsetus colonensis	—	—	—	3	9	24	12	1	—	—	—	—
lyolepis	—	—	—	1	5	8	23	12	6	1	—	—
filifera	—	—	—	—	—	5	4	4	—	—	—	—

* When the counts exceed the number of specimens listed in the text, the rakers were counted on both anterior arches.

Table III. Frequency Distribution of Gill Rakers on Lower Limb of First Arch in *Anchoa*.*

	Number of Gill Rakers																		
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
spinifer	4	11	24	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
argenteus	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—
duodecim	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—
trinitatis	—	—	—	—	1	3	7	8	—	—	—	—	—	—	—	—	—	—	—
cayorum	18	40	22	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
pectoralis	—	—	3	13	4	2	—	—	—	—	—	—	—	—	—	—	—	—	—
mitchilli mitchilli	—	—	—	—	—	4	21	45	70	54	21	6	—	—	—	—	—	—	—
mitchilli diaphana	—	—	—	—	—	12	64	125	92	46	10	3	—	—	—	—	—	—	—
parva	—	—	—	—	—	—	—	—	7	10	14	13	1	—	—	—	—	—	—
januaria	—	—	—	—	—	—	—	—	2	4	4	5	—	—	—	—	—	—	—
choerostoma	—	—	—	—	—	—	—	—	10	12	9	6	—	—	—	—	—	—	—
tricolor	—	—	—	—	—	—	—	—	—	11	20	25	8	2	—	—	—	—	—
cubana	—	—	—	—	—	—	—	—	3	2	11	6	8	18	8	7	2	2	2
ginsburgi	—	—	—	—	—	2	3	8	—	—	—	—	—	—	—	—	—	—	—
lamprotaenia	—	2	26	94	82	31	8	5	—	—	—	—	—	—	—	—	—	—	—
hepsetus hepsetus	—	—	—	9	27	97	93	47	2	1	—	—	—	—	—	—	—	—	—
hepsetus colonensis	—	—	—	—	4	15	25	4	—	—	—	—	—	—	—	—	—	—	—
lyolepis	—	—	—	—	4	11	14	11	7	5	5	4	—	—	—	—	—	—	—
filifera	—	—	—	—	—	3	3	12	1	—	—	—	—	—	—	—	—	—	—

* When the counts exceed the number of specimens listed in the text, the rakers were counted on both anterior arches.

Anchoa spinifer (Cuvier and Valenciennes) 1848

Sardine

Figure 27

Study Material. Many specimens, 30–175 mm TL: from the Atlantic at the Gatun Locks, Canal Zone; Port-of-Spain, Trinidad; and Bahia, Cachoeira, and Santos, Brazil; from the Pacific at Pedro Miguel and Miraflores locks, Canal Zone; Panama Bay; and Guayaquil, Ecuador.

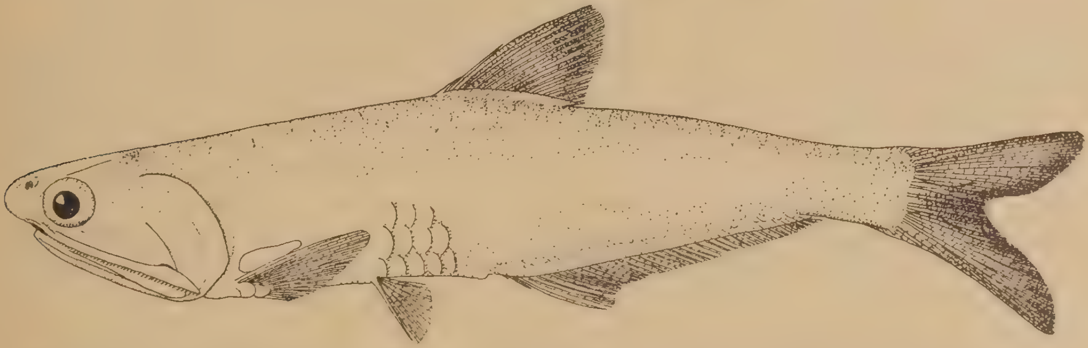

FIGURE 27. *Anchoa spinifer*, 90 mm TL, from Gatun Locks, Canal Zone, USNM 127560. Drawn by Louella E. Cable.

Distinctive Characters. The long anal fin, the dorsal's high rays in the anterior part, the dorsal's forward position, the long low head and especially its prolonged postorbital portion, the long narrow cheek, and the dark margin of the caudal fin distinguish this species from all of its relatives. Large examples generally are proportionally deeper than small ones, and generally Atlantic specimens are rather deeper than Pacific ones. However, there is so much overlapping that, with the material at hand, specimens from the opposite coasts cannot be separated by this character, nor seemingly by any other. The pectoral fin also varies greatly in proportional length, but this also seems to be an individual variation. Nevertheless, the comparison is not satisfactory because nearly all of the Atlantic specimens are old and faded, not in good condition.

Description. Proportional dimensions in per cent of standard length, and counts, based on 11 Atlantic specimens and 15 Pacific specimens, 66–175 mm TL.

Body: depth 19.2–25.
Head: length 25–27.8.
Snout: length 3.0–4.3.
Eye: diameter 4.5–6.25.
Postorbital: distance 14.9–16.6.
Maxillary: length 20.8–23.2.
Mandible: length 19.6–20.3.

Anal fin: length of base 33.1–36.6.
Pectoral fin: length 17.5–20.

Scales: *ca.* 45.
Gill rakers: 12–16+15–18.
Fin rays: dorsal 14–16; anal 35–40; pectoral 12–14.
Vertebrae: 43–45 (15 specimens).

Body quite elongate, rather strongly compressed, its depth 4.0–5.2 in SL, increasing somewhat with age and growth. Head 3.6–4.0 in SL, its depth scarcely exceeding its postorbital length. Snout projecting nearly its full length beyond mandible, 6.6–7.5 in head. Eye small, 4.2–5.0. Postorbital part of head long, 1.5–1.7 in head. Maxillary long and pointed, reaching to or nearly to margin of opercle, 1.1–1.25 in head. Mandible 1.22–1.4. Cheek in large specimens much longer than snout and eye, about equal to snout and eye in specimens about 80 mm TL; posterior angle sharp, about 30°.

Dorsal fin high anteriorly, its longest ray reaching far beyond tip of last ray if deflexed, its origin generally rather more than an eye's diameter nearer to tip of snout than to base of caudal. Anal 2.8–3.0 in SL, its origin generally somewhat in advance of middle of dorsal base. Pelvic reaching about 66 % of distance to anal, inserted about equidistant between origin of anal and base of pectoral. Pectoral large, reaching to, and generally beyond, base of pelvic, 1.3–1.5 in head. Axillary scale of pectoral broad, reaching somewhat beyond midlength of fin, 2.4–2.9 in head.

Color. In alcohol, pale above. Lower half of side silvery. Young sometimes with a poorly defined silvery lateral band. Back with dusky punctulations. Fresh specimens 125 mm TL and upward (taken in Pedro Miguel and Miraflores locks, Canal Zone) bright orange, this color contrasting conspicuously with black margin of caudal fin.

Size. The largest specimen seen, about 175 mm TL or 7 inches (caudal fin damaged) and 138 mm SL, is probably near the maximum size attained.

Range and Habitat. The range in the Atlantic, so far as known, extends from Panama to Santos, Brazil. On the Pacific side it is known from Panama Bay to Guayaquil, Ecuador. The West Indies has been included in the general range (7: 410), but I have seen no specimens from that locality and have found no other record. In rather extensive collecting on the Atlantic coast of Panama (during the dry seasons), only a single small specimen was secured; but on the Pacific side it was exceedingly abundant in Pedro Miguel and Miraflores locks when these were drained in 1937; however, it was not seen elsewhere during four different seasons of collecting. The water ranges from near oceanic salinity in the lower flights of Miraflores Locks (at sea level) to fresh in Pedro Miguel Locks.

Synonyms and References:

Engraulis spinifer Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 39 (orig. descr.; type local. Cayenne, French Guiana); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 394 (descr., type local.); Steindachner, Ichthyol. Beitr., 8, 1879: 58 (descr.; Guiana; Bahia and Cachoeira, Brazil; w. coast of Panama).

Stolephorus spinifer Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 448 (descr., range); Eigenmann, Mem. Carneg. Mus., *5*, 1912: 449 (synon., descr., Georgetown, British Guiana); Puyo, Bull. Soc. Hist. nat. Toulouse, *70*, 1936: 65, 163 (diagn., habitat French Guiana); Puyo, Bull. Soc. Hist. nat. Toulouse, *80*, 1945: 105, fig. 3 (descr., French Guiana); Puyo, Faune Emp. Franç., *12*, Poiss. Guyane Franç., 1949: 156, fig. 79 (descr., French Guiana).

Anchovia spinifera Gilbert and Starks, Mem. Cal. Acad. Sci., *4*, 1904: 46, pl. 8, fig. 15 (descr. based on two from Panama Bay); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 207 (synon., descr., range); von Ihering, Rev. Industr. Anim., Anno 1 (3), 1930: 233 (ref., diagn.); Hildebrand, Zoologica, N. Y., *24* (1), 1939: 25, 30, 36 (Panama Canal locks).

Anchoviella spinifera Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 409 (descr., Cachoeira, Brazil; "Panama" presumably Pacific coast; "West Indies" in range); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 50 (range); Fowler, Arqu. Zool. estad. São Paulo, *3*, 1941: 134 (refs., Brazil).

Anchoa spinifer Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 38, fig. 10 (synon., descr., range, local abund.).

Anchoa argenteus Schultz 1949

Figure 28

Study Material. Known only from the type, *ca.* 115 mm TL (caudal fin damaged), 94 mm SL, from Lake Maracaibo, off Pueblo Viejo, Venezuela.

Distinctive Characters. This species is closely related to *A. spinifer*, with which it agrees in the shape and position of the dorsal fin, the long low head, the long narrow cheek, and in many other respects. But it differs significantly from that species (so far as can be determined from a single specimen) in having fewer anal rays, in a slightly greater number of gill rakers on the lower limb, in the longer mandible, in the shorter pectoral fins, and in the absence of a dark margin on the caudal fin.

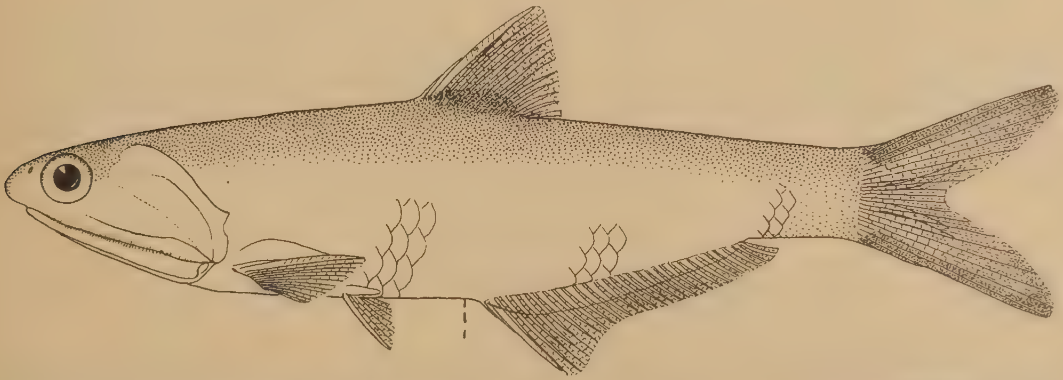

FIGURE 28. *Anchoa argenteus*, type specimen, 94 mm TL, from Maracaibo Basin, Venezuela, USNM 121777. Drawn by A. M. Awl.

Description. Proportional dimensions in per cent of standard length, and counts, based on the type specimen, 94 mm SL.

Body: depth 22.5.
Head: length 26.5.
Snout: length 4.25.
Eye: diameter 5.55.
Postorbital: distance 18.5.
Maxillary: length 23.5.
Mandible: length 20.6.

Anal fin: length of base 32.
Pectoral fin: length 15.5.

Scales: *ca.* 43.
Gill rakers: 14+19.
Fin rays: dorsal 16; anal 32; pectoral 13.

Body elongate, rather strongly compressed, its depth 4.5 in SL. Head 3.75, its depth a little greater than its postorbital length. Snout shorter than eye, projecting much more than half of its length beyond tip of mandible, 6.25 in head. Eye small, 4.8. Postorbital length 5.4. Maxillary moderately pointed, reaching margin of opercle, 1.15 in head. Mandible 1.3. Cheek narrow, much longer than snout and eye, its posterior angle about 30°. Gill rakers at angle of first arch about $66^{0}/_{0}$ of length of eye, with strong serrae on inner edge, somewhat expanded at tips.

Dorsal fin moderately elevated anteriorly, its margin nearly straight, its longest rays reaching well beyond the last ray if deflexed, its origin about an eye's diameter nearer to tip of snout than to base of caudal. Anal fin fairly long, its origin under middle of dorsal base, its base notably longer than head, 3.1 in SL. Pelvic fin reaching a little more than halfway to origin of anal, inserted a little nearer to base of pectoral than to origin of anal, 3.1 in head. Pectoral fin reaching beyond base of pelvic by about half of diameter of eye, 6.5 in SL, 1.7 in head. Axillary scale of pectoral extending to beginning of distal third of fin, 2.55 in head.

Color. In alcohol, somewhat straw-colored on back, changing rather abruptly to silvery on the side at level of upper margin of eye; back with dusky punctulations, these extending onto basal $66^{0}/_{0}$ or so of dorsal fin, and onto outer rays of caudal fin.

Range. Known only from Lake Maracaibo, off Pueblo Viejo, Venezuela.

Reference:

Anchoa argenteus Schultz, Proc. U. S. nat. Mus., *99*, 1949: 45, fig. 5 (orig. descr.; type local. Lake Maracaibo, off Pueblo Viejo, Venezuela; type USNM 121777).

Anchoa duodecim (Cope) 1869

New Jersey Anchovy

Study Material. Known only from the type, 97 mm long (77 mm SL), taken at Beesley's Point, New Jersey, ANSP 1363.

Distinctive Characters. This species has been considered identical with *A. mitchilli.* However, it differs strikingly from other local forms in its deep body, high dorsal fin, the positions of the dorsal and anal fins, and in several other respects. It is of interest that the species has never reappeared in collections.

Description. Proportional dimensions in per cent of standard length, and counts, based on the type specimen, 77 mm SL.

Body: depth 25.
Head: length 27.
Snout: length 4.7.
Eye: diameter 5.8.
Postorbital: distance 16.3.
Maxillary: length 22.
Mandible: length 21.

Anal fin: length of base 25.
Pectoral fin: length 18.2.

Scales: partly lost, *ca.* 38.
Gill rakers: 14 or 15+20.
Fin rays: dorsal 14; anal 30; pectoral 12.

Body rather short, deep, and well compressed; dorsal profile more strongly convex than ventral profile. Head short, deep, its depth equal to its postorbital length and half of eye. Snout rather short, projecting a little less than a third of its length beyond mandible, 5.8 in head. Eye small, 4.7. Postorbital 1.6 in head. Maxillary fairly short, reaching joint of mandible, broad and abruptly pointed, 1.25 in head. Mandible 1.3. Cheek as long as snout and eye, its posterior angle about 35°. Gill rakers at angle nearly as long as eye.

Dorsal fin high anteriorly, its longest rays reaching far beyond tip of last ray if deflexed, its origin an eye's diameter nearer to tip of snout than to base of caudal. Anal rather long and low, its origin half of an eye's diameter posterior to end of dorsal base, and about equidistant between base of caudal and base of pectoral, its base 4.0 in SL. Pelvic fin large, shorter than pectoral by diameter of pupil, extending about 66 % of the distance to origin of anal, inserted a little nearer to joint of mandible than to origin of anal. Pectoral reaching base of pelvic, 1.5 in head. Axillary scale of pectoral a little more than half of the fin length, 2.7 in head.

Color. Old preserved specimen grayish brown above. Lower two-thirds of side silvery; no lateral band and no punctulations visible.

Range. Known only from Beesley's Point, New Jersey.

Synonyms and References:

Engraulis duodecim Cope, Trans. Amer. philos. Soc., *13* (2), 1869: 405 (orig. descr.; type local. Beesley's Point, New Jersey; type ANSP 1363).

Anchovia duodecim Fowler, Rep. N. J. St. Mus. (1905), 1906: 111 (descr.); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 219; Fowler, Proc. biol. Soc. Wash., *33*, 1920: 148.

Anchoa duodecim Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 46 (synon., descr. based on type).

Anchoa trinitatis (Fowler) 1915

Figure 29

Study Material. A total of 19 specimens, including the type, from Trinidad and Venezuela, ANSP, UMMZ, USNM.

Description. Proportional dimensions in per cent of standard length, and counts, based on 10 specimens from *Study Material*, 55–110 mm TL.

Body: depth 22–25.6.
Head: length 24.3–27.
Snout: length 3.9–4.35.
Eye: diameter 6.75–7.6.
Postorbital: distance 11.7–13.3.
Maxillary: length 16.6–22.
Mandible: length 16.4–19.

Anal fin: length of base 29.4–33.2.
Pectoral fin: length 16.6–19.

Scales: *ca.* 38–42.
Gill rakers: 15–19 + 18–22.
Fin rays: dorsal 13 or 14; anal 26–30; pectoral 13 or 14.
Vertebrae: 41 (1 specimen).

Body rather strongly compressed, its greatest thickness about equal to depth of caudal peduncle, its depth 3.9–4.5 in SL. Head short, 3.7–4.1 in SL, its depth equal to its postorbital length and about 66% of diameter of eye. Snout extending about 66% of its length beyond mandible, 5.7–6.6 in head. Eye 3.4–3.7. Postorbital 1.9–2.1 in head. Maxillary pointed, extending nearly to margin of opercle, 1.2–1.4 in head. Mandible 1.4–1.53. Cheek about as long as eye and half of snout, its posterior angle about 40°.

Dorsal fin moderately high anteriorly, its longest rays reaching beyond tip of last ray if deflexed, its origin equidistant between base of caudal and a point at anterior half of eye. Anal origin under, or somewhat in advance of, middle of dorsal base, its base 3.0–3.4 in SL. Pelvic reaching fully halfway to anal, inserted a little nearer to origin of anal than to base of pectoral. Pectoral sometimes not quite reaching to pelvic, 1.35–1.52 in head. Axillary scale of pectoral rather broad at base, scarcely extending to vertical at midlength of fin, 2.8–3.6 in head.

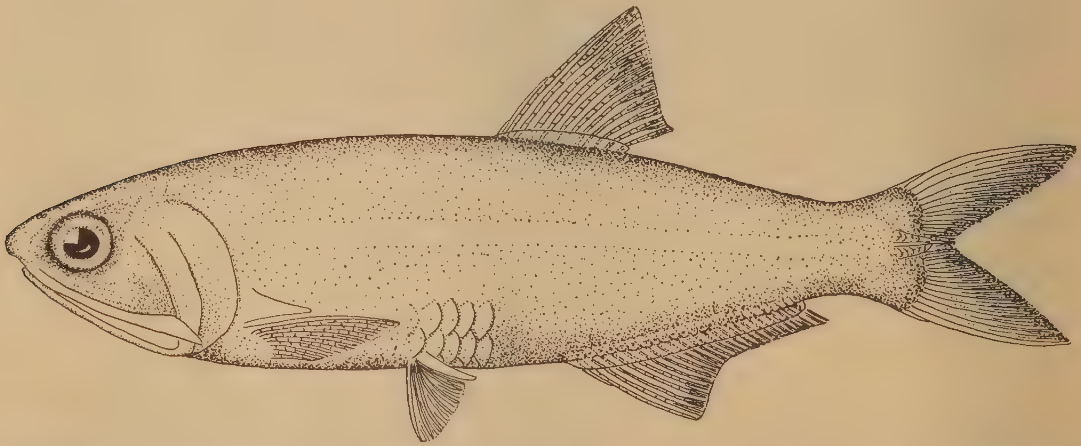

Figure 29. *Anchoa trinitatis*, type specimen, from Port-of-Spain, Trinidad, ANSP 45083, modified after Fowler (1915: 527, fig. 3). Drawn by Alice C. Mullen.

Color. In alcohol, pale above. Side of head and lower part of body silvery. Silvery lateral band faint, narrower than pupil, missing in specimens presumably preserved originally in formalin. Back and upper surface of head with dusky punctulations, sometimes forming two almost continuous lines posterior to dorsal fin.

Size. The largest individual seen is 110 mm TL.

Range. So far as known, this species is confined to four localities: Port-of-Spain and Vessigney, Trinidad; Laguna de Tacarigua (on coast 85 miles east of Caracas), and Rio Caño de Sagua, Sinamaica, Venezuela.

Synonyms and References:

Anchovia trinitatis Fowler, Proc. Acad. nat. Sci. Philad., 1915: 527, fig. 3 (orig. descr.; type local. Port-of-Spain, Trinidad; type ANSP 45083).

Anchoviella trinitatis Fowler, Proc. Acad. nat. Sci. Philad., *83*, 1931: 392 (Vessigney, Trinidad).
Anchoa trinitatis Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 96, fig. 40 (descr. cf. several related species, range); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 44 (synon., specimens and local. listed; counts of rays, gill rakers, vert., and scales).

Anchoa cayorum (Fowler) 1906

Key Anchovy, Manjúa (Cuba)

Figure 30

Study Material. A total of 26 or more specimens, 50–85 mm TL, from Tortugas, Florida; Cabañas Bay, Cuba; Cozumel Island, off Yucatán, México; Belize, British Honduras; and Hailer's Rock, Florida Keys (type and paratype).

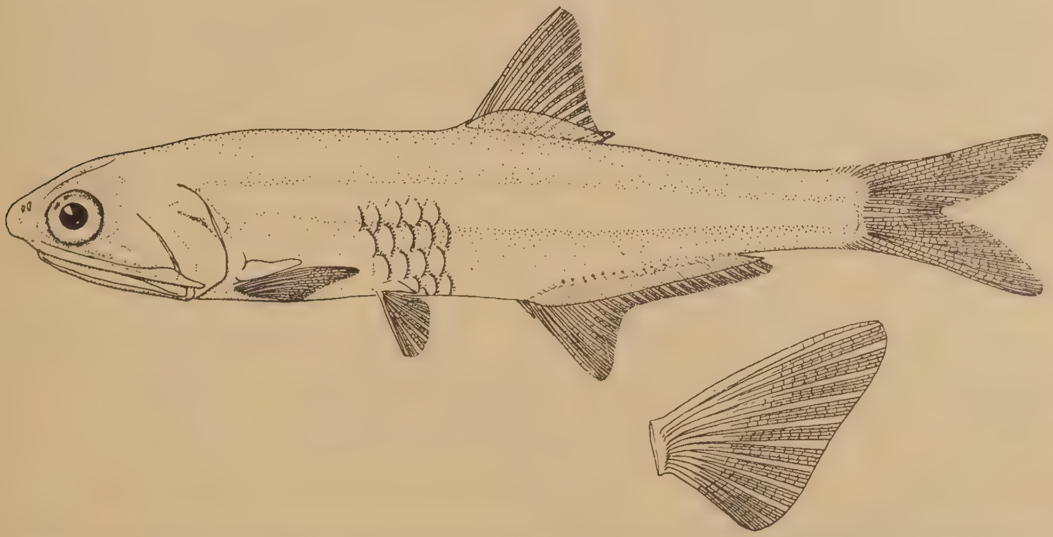

FIGURE 30. *Anchoa cayorum*, 85 mm TL, 68 mm SL, from Cabañas Bay, Cuba, USNM 82341, with pectoral fin enlarged. Drawn by Louella E. Cable.

Distinctive Characters. Museum specimens generally have been identified with *A. mitchilli*, presumably because of the long anal fin, but *cayorum* differs in the larger size it attains (largest seen 85 mm), in the notably fewer gill rakers, and in the much broader and more prominent silvery lateral band.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 50–85 mm TL.

Body: depth 18–21.
Head: length 25–28.5.

Snout: length 4.3–5.0.
Eye: diameter 5.8–7.4.

Postorbital: distance 13.3–15.3.
Maxillary: length 19.2–22.5.
Mandible: length 18.5–20.
Anal fin: length of base 25–29.3.
Pectoral fin: length 13.9–16.6.

Scales: *ca.* 39–42.
Gill rakers: 13–15+15–17 (rarely 18).
Fin rays: dorsal 13–15; anal 26–28 (rarely 25 or 29); pectoral 12 or 13.
Vertebrae: 43 (3 specimens).

Body slender, moderately compressed, its depth 4.75–5.5 in SL. Head 3.5–4.0 in SL, its depth equal to its postorbital length and about half of eye. Snout projecting about 66% of its length beyond tip of mandible, 5.0–6.0 in head. Eye 3.5–4.25. Postorbital 1.65–2.0 in head. Maxillary long and pointed, its upper margin straight, reaching nearly or quite to margin of opercle, 1.1–1.35 in head. Mandible 1.2–1.4. Cheek equal to, or a little longer than, eye and 75% of snout, its posterior angle rather sharp, about 40°.

Dorsal fin with the longest rays reaching well beyond tip of last ray if deflexed, its origin about equidistant between base of caudal and anterior margin of eye. Anal fin with origin under beginning of second fourth of dorsal, its base 3.4–4.0 in SL. Pelvic inserted somewhat nearer to base of pectoral than to origin of anal. Pectoral falcate, sometimes failing to reach base of pelvic by diameter of pupil, occasionally reaching nearly to base of pelvic, the first (uppermost) ray generally as long as the second and about twice the last ray, 1.5–1.9 in head. Axillary scale of pectoral scarcely reaching beyond midlength of pectoral, 3.0–3.5 in head.

Color. In alcohol, pale. Side of head silvery. Silvery lateral band bright, about as wide as eye.

Range and Habitat. The range extends from the Florida Keys, where it is apparently rather rare, to Cuba, Yucatán, and British Honduras. The specimens examined were apparently taken in shallow water, near the shore.

Synonyms and References:

Stolephorus mitchilli Bean, Bull. U. S. Fish Comm. (1888), *8*, 1890: 206 (Cozumel I., off Yucatán, México; specimens re-exam. and found to be *A. cayorum*).

Anchovia choerostoma cayorum Fowler, Proc. Acad. nat. Sci. Philad., *58*, 1906: 85, fig. 4 (orig. descr.; type local. Hailer's Rock, Florida Keys; type ANSP 30613).

Anchovia cayorum Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 219 (types relisted).

Anchoviella cayorum Jordan, Evermann and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (synon.).

Anchoa cayorum Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 50, fig. 17 (synon., descr., relation., range, type material re-exam.).

Anchoa pectoralis Hildebrand 1943

Study Material. Only the type material, 64 specimens, 43–65 mm TL, from Vigia, Brazil, MCZ 18004, listed for "Brazil, Louis Agassiz."

Distinctive Characters. This species is closely related to *A. mitchilli diaphana*, *A. parva*, and *A. januaria*, from all of which it differs in the more numerous pectoral rays. Other differences are evident in the descriptions and tables.

Description. Proportional dimensions in per cent of standard length based on 7 specimens, the counts based on many more. As the state of preservation is not very good, some of the proportions may not be entirely true.

Body: depth 19.5–23.0.
Head: length 23.8–26.2.
Snout: length 3.35–4.16.
Eye: diameter 6.7–8.0.
Postorbital: distance 12.9–13.7.
Maxillary: length 17.7–19.0.
Mandible: length 15.8–17.6.

Anal fin: length of base 23.4–25.6.
Pectoral fin: length 17.8–18.8.

Scales: *ca.* 35–40.
Gill rakers: 13 or 14 + 17–19.
Fin rays: dorsal 14–16; anal 25–27; pectoral 15–17 (most frequently 16).
Vertebrae: 42 (2 specimens).

Body moderately slender, strongly compressed, its depth 4.35–5.1 in SL. Head 3.8–4.2 in SL, its depth nearly equal to its length without snout. Snout short, projecting about half of its length beyond mandible, 6.0–7.0 in head. Eye 3.2–3.7. Postorbital 1.75–2.0 in head. Maxillary bluntly pointed, its upper margin rounded, reaching somewhat beyond joint of mandible, 1.2–1.4 in head. Mandible 1.4–1.6. Cheek about as long as eye, its posterior angle broad, about 50°.

Dorsal fin with longest rays reaching to, and occasionally beyond, tip of last ray if deflexed, its origin generally a little nearer to base of caudal than to middle of eye. Anal with origin generally under middle of dorsal, its base 3.9–4.25 in SL. Pelvic reaching only about halfway to anal, inserted equidistant between origin of anal and base of pectoral, or slightly nearer the former. Pectoral falcate, reaching nearly to base of pelvic, 1.3–1.4 in head. Axillary scale of pectoral pointed, about 66% of length of fin, 2.5 in head.

Color. Old specimens in alcohol, brownish silvery. A prominent silvery lateral band present, about as wide as eye. Back with dark dots, in more or less distinct longitudinal rows. Base of anal with black dots; caudal with dark dots and with a dark margin.

Range. Known only from the type material from Vigia, Brazil, collected in 1865 or 1866 by the Thayer Expedition of Harvard University. [Stieler's Atlas lists the name Vigia for two places in Brazil, one at the mouth of Rio Pará (Tocantins), the other well inland on Rio Jequitinhonha in the Province of Minas Gerais.—Y.H.O.].

Synonyms and References:

Anchoviella mitchilli Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 405 (descr., distr., MCZ 18004).

Anchoa pectoralis Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 52, fig. 18 (orig. descr.; type local. Vigia, Brazil; type MCZ 35276).

Anchoa mitchilli (Cuvier and Valenciennes) 1848

Bay Anchovy

Figures 31, 32

Study Material. A total of 100 specimens, 52–102 mm TL; for characters considered important, such as body depth, pectoral length, number of vertebrae, gill rakers, and anal rays, many more were used; taken at many places from Woods Hole, Massachusetts, to Yucatán, México.

Distinctive Characters. The nearest relative is *A. parva*, a southern species that occurs in the West Indies and on the mainland coast from Panama to Venezuela. This relationship is discussed in the account dealing with *parva* (p. 181).

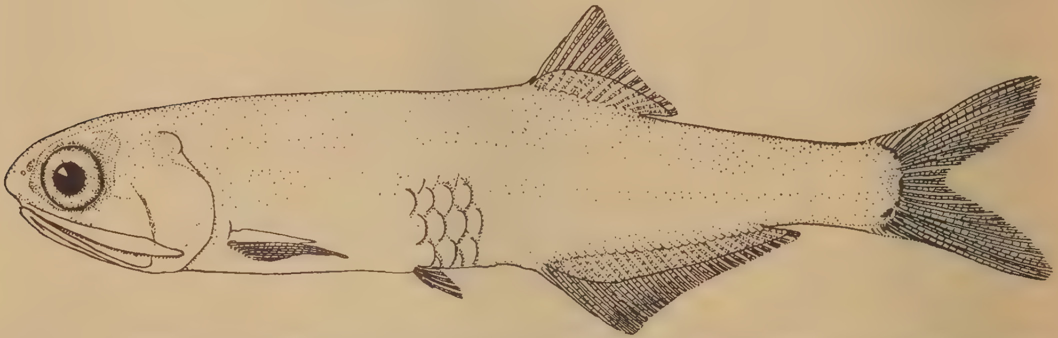

FIGURE 31. *Anchoa mitchilli mitchilli*, 85 mm TL, from Woods Hole, Massachusetts, USNM 125582. Drawn by Louella E. Cable.

Description. Proportional dimensions in per cent of standard length, and counts, based on *Study Material.*

Body: depth 16–27.
Head: length 22–26.5.
Snout: length 3.7–7.25.
Eye: diameter 5.8–8.2.
Postorbital: distance 11–13.5.
Maxillary: length 17.5–21.
Mandible: length 16.5–18.5.
Anal fin: length of base 25–30.

Pectoral fin: length 12–20.

Scales: (generally lost in preserved specimens) *ca.* 38–44.
Gill rakers: 15–19+20–26.
Fin rays: dorsal 14–16; anal 24–30; pectoral 11 or 12.
Vertebrae: 38–44 (1,233 specimens).

BODY rather slender, moderately compressed, its greatest thickness usually exceeding the depth of caudal peduncle, its depth 3.65–6.3 in SL. HEAD 3.75–4.5, its depth equal to its length without snout and fourth of eye. SNOUT short, projecting not more than a fourth of its length beyond tip of mandible, 5.0–7.0 in head. EYE 2.9–3.9. POSTORBITAL short, 1.8–2.1 in head. MAXILLARY pointed, extending nearly to margin of opercle, 1.1–1.3 in head. CHEEK short and broad, about as long as eye, its posterior angle approximately 60°. GILL RAKERS somewhat shorter than eye.

DORSAL fin rather low, with nearly straight margin, its last ray scarcely longer than the one immediately before it, its longest rays failing to reach its tip if depressed, the origin varying between a little nearer to caudal base than to upper anterior angle of gill opening and equidistant between caudal base and posterior margin of eye. ANAL usually originating somewhat posterior to dorsal origin, its base 3.3–4.0 in SL. PELVIC fin very small, not quite reaching halfway to origin of anal, inserted nearer to anal origin than to pectoral base by diameter of pupil. PECTORAL variable, failing to reach base of pelvic by a distance equal to, or even greater than, diameter of eye in northern specimens, sometimes reaching pelvic base in southern fish, 1.4–1.85 in head. AXILLARY SCALE of pectoral rather narrow, 2.3–3.0 in head.

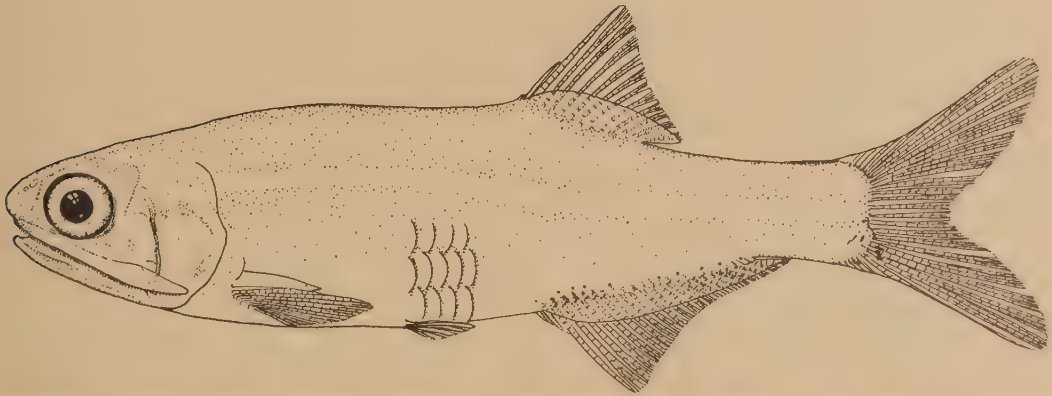

FIGURE 32. *Anchoa mitchilli diaphana*, 72 mm TL, from Grand Isle, Louisiana, USNM 119790. Drawn by Louella E. Cable.

Color. Preserved specimens, straw-colored above. Lower parts pale silvery. Sides of head bright silvery. Middle of side with a silvery band, often nearly as wide as eye in northern specimens, generally narrower in southern ones. Back with dusky punctulations, arranged in two more or less definite rows posterior to dorsal fin; base of anal with dark spots continued as a single unbroken median ventral line on caudal peduncle; caudal with many dark points. Color in life, greenish with bluish reflections above; lower parts pale; abdominal walls translucent.

Size. A total length of 100 mm (4 in.) is seldom exceeded, the usual length being around 75 mm (3 in.). The largest examples measured were taken in New York, where this species evidently grows larger than in the southern part of its range, for the largest specimen among thousands from the Gulf of Mexico was only 75 mm long.

Development and Growth. The egg generally is slightly oblong, but occasionally round; the major axis is about 0.75 mm and the minor one about 0.62 mm. It is transparent and has no oil globule. The yolk consists of separate masses that appear as large cells under the microscope, a character that seems to be common to all species of Engraulidae whose eggs have been studied. The egg floats at or near the surface and hatches in about 24 hours at room temperature, at least at Beaufort, North Carolina, during early summer.[4]

The newly hatched fish, 1.8–2.0 mm long, is rather slender, perfectly transparent, and has no pigment spots. The yolksac is absorbed within about two days, and the large mouth, which is terminal at this stage, then seems to be functional. The projecting snout is not developed until the young fish reaches a length of about 20–25 mm. But the fins are sufficiently developed at a length of about 15 mm to permit a fairly accurate enumeration of the rays. The number of anal rays and the relative positions of the dorsal and anal fins are very useful in identifying the postlarvae with the adults.

The early young of the season seem to become sexually mature during their first summer, for specimens 45–60 mm long that remained quite transparent, taken late in July and during the first half of August at Beaufort, N. C., contained well developed roe.

Spawning. In the vicinity of Beaufort, N. C., spawning takes place at least from early spring to midsummer. The eggs were taken in tows there as early as April 21 (in 1930) and as late as July 15 (in 1929), while gravid fish were seen as late as August 12 (from my unpublished notes).

Food. The food apparently consists mostly of *Mysis* and copepods, the latter being the sole food of the young. Other items taken are small fish, gastropods, and isopods (5: 110).

Enemies. This fish, which is exceedingly numerous in a large part of its range, is preyed upon extensively by predatory fish and water birds.

Variation. The variation within this species is so great that I recognized a northern subspecies, *A. mitchilli mitchilli*, and a southern one, *A. mitchilli diaphana* (3: 87–94). The specimens from the southern part of the range have rather consistently deeper and more strongly compressed bodies, fewer gill rakers, fewer vertebrae, a longer pectoral fin, and a narrower silvery lateral band. These differences are shown by comparing the characters of a small lot of specimens from Woods Hole, Massachusetts, with another lot from Grand Isle, Louisiana, which show the widest divergence (Table IV). Complete intergradation of the two subspecies occurs in the midsection of their range, as in North and South Carolina.

Commercial Importance. This Anchovy is used as bait and to a limited extent in the preparation of anchovy paste. However, it is important chiefly as forage for many important foodfishes. As this fish usually occurs in schools and is a rather sluggish swimmer, it is an easy prey of many predators.

Range and Habitat. Cape Cod, Massachusetts (rarely northward into the Gulf of Maine), and southward to Yucatán, México. Brazilian records probably are referable either to *A. parva* or *A. januaria*. While *A. mitchilli* occurs along the outer and exposed

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4. The information as to the eggs and young fish is in part from Kuntz (9: 13–19) and in part from my field notes.

Table IV. Comparison of Divergent Specimens of *A. mitchilli.*

WOODS HOLE, MASSACHUSETTS	GRAND ISLE, LOUISIANA
Eight specimens, 62–85 mm TL	Sixteen specimens, 48–76 mm TL.
Depth, 19–21 % of SL.	*Depth,* 23–26 % of SL.
Greatest thickness of body, usually exceeding depth of caudal peduncle.	*Greatest thickness of body,* less than depth of caudal peduncle.
Pectoral fin, 13–13.5 % of SL.	*Pectoral fin,* 16.5–17.5 % of SL.
Gill rakers, 24–28 on lower limb.	*Gill rakers,* 21–23 on lower limb.
Vertebrae, 43 or 44 in four specimens.	*Vertebrae,* 39–41 in nine specimens.
Silvery lateral band about as broad as eye.	Silvery lateral band scarcely broader than pupil.

beaches at Beaufort, N. C., at least to a depth of 15–20 fms., it is found more often in inside waters, especially in areas with muddy bottoms and brackish water. The distribution is so general that the fish may be expected also in "grassy" areas and along sandy beaches.

Migrations. It was formerly thought that this species, as well as several other anchovies, migrated northward and southward with the seasons. This theory was based on the fact that in the northern part of the range, as at Woods Hole, Massachusetts, the fish is present only during the summer. However, it has been shown (*3*: 87–94) that virtually every section of the coast within the range of *mitchilli* has a distinctive population, which suggests that whatever migration takes place is an inshore and offshore movement.

Details of Occurrence. The most northern records are for Casco Bay, Maine, and for Provincetown at the tip of Cape Cod, Massachusetts; these have been based on stray specimens only. But it is described as abundant in the Woods Hole region and in Rhode Island waters (both adults and larvae), common in New York waters, exceedingly abundant (often in large schools) at many New Jersey localities, and second in abundance (if not the most abundant) in Chesapeake Bay. It has been recorded for North Carolina, South Carolina,[5] and Georgia, and it is at least tolerably plentiful in the Indian River on the eastern coast of Florida. No certain evidence has been found of its presence among the Florida Keys, but it has long been known to be plentiful in the inlets and passes all along the western coast of Florida. It has been recorded for so many localities in Mississippi, Louisiana (Cameron, Grand Isle, and Lake Ponchartrain), Texas (Galveston, Corpus Christi, Dickinson Bayou), and México (Vera Cruz, Rio Pánuco, Tampico) as to prove it practically universal in suitable situations all around the coastline of the Gulf of Mexico to Yucatán. But present indications are that Yucatán marks the southern boundary of its range, there being no reliable record of its presence anywhere to the southward around the Central or South American shores of the Caribbean.

Reports of it for Cuba (*20*: 57; *17*: 421; *7*: 405) on the strength of two specimens from Poey in the Museum of Comparative Zoology seem to have been based on a misinterpretation of what Poey wrote about this Anchovy. Actually the locality given in the Museum catalogue for these specimens is "United States," to which a label in the bottle in my handwriting adds "Sent to Poey by Gill for comparison."

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[5] The Museum of Comparative Zoology has a specimen from Charleston, collected by Louis Agassiz.

Synonyms and References:

Engraulis mitchilli Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 50 (orig. descr.; type local. New York; mentions *Engraulis louisiana*[6]); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 391 (synon., descr., range).

Stolephorus mitchilli Jordan and Gilbert, Proc. U. S. nat. Mus. (1882), *5*, 1883: 248 (descr., synon., includ. *Engraulis duodecim* Cope, a valid species; Galveston, Texas; Pensacola, Florida; Woods Hole, Massachusetts); Swain, Bull. U. S. Fish Comm. (1882), *2*, 1883: 57 (range; Princetown and Woods Hole, Massachusetts; Pensacola, Florida; Lake Ponchartrain, Louisiana; Galveston, Texas; and Cuba, which is probably *A. parva*; includ. *Engraulis duodecim* Cope); Bean, Bull. U. S. Fish Comm. (1887), *7*, 1888: 149 (Ocean City, Beesley's Pt., and Longport, New Jersey; local abund.); Henshall, Bull. U. S. Fish Comm. (1889), *9*, 1891: 373 (very abund. in most inlets and passes of Florida west coast); Smith, Bull. U. S. Fish Comm. (1892), *12*, 1894: 361 (abund. in New Jersey; relation. to commerc. fishes); Evermann and Kendall, Bull. U. S. Fish Comm. (1892), *12*, 1894: 105 (Galveston, Corpus Christi, Dickinson Bayou, Texas); Moore, Bull. U. S. Fish Comm. (1892), *12*, 1894: 359 (near Sea Isle City, New Jersey); Lönnberg, Oefvers. Svensk. Vet. Akad. Forh., *51*, 1894: 115 (St. Petersburg, Florida); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 446 (descr., range, synon., includ. *Engraulis duodecim* Cope); Evermann and Bean, Rep. U. S. Comm. Fish. (1896), 1897: 241 (many at Cocoa and St. Lucia on Indian R., Florida); Smith, Bull. U. S. Fish Comm. (1897), *17*, 1898: 92 (Woods Hole, Massachusetts); Smith and Bean, Bull. U. S. Fish Comm. (1898), *18*, 1899: 184 (Potomac R. at Bryants Pt., Maryland); Evermann, Rep. U. S. Comm. Fish. (1898), 1899: 309 (Baldwin Lodge, Mississippi; Lake Lapourde, Louisiana); and (1899), 1900: 56 (Florida); Bean, Rep. Forest Comm. N. Y. (1901), 1902: 311 (refs., range, New York, econ. import.); Bean, Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 218 (descr., range, a forage fish; New York); Latham, Copeia, 1917 (Orient, Long Island, New York); Breder, Zoologica, N. Y., *2*, 1922: 338 (Sandy Hook Bay, New Jersey).

Anchovia mitchilli Fowler, Rep. N. J. St. Mus. (1905), 1906: 110, fig. (descr., Delaware R. off Ft. Delaware, Delaware; Beesley's Pt. and Ocean City, New Jersey); and (1906), 1907: 267 (Sea Isle City, New Jersey; taken for bait); Smith, N. C. geol. econ. Surv., *2*, 1907: 134 (synon., descr., range, Morehead City, North Carolina); Jordan and Dickerson, Proc. U. S. nat. Mus., *34*, 1908: 12 (diagn., mouth of Rio Pánuco, Tampico, México); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7*, 1908: 42 (Casco Bay, Maine; Provincetown and Woods Hole, Massachusetts; Rhode Island); Weymouth, Proc. U. S. nat. Mus., *38*, 1910: 136 (Cameron, Louisiana); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 219 (Woods Hole, Massachusetts; Seaside Park, Beesley's Pt., Carson's Inlet, New Jersey; Ft. Delaware, Delaware; Tolchester Beach, Maryland); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31* (2), 1913: 743 (Woods Hole, Massachusetts); Kuntz, Bull. U. S. Bur. Fish. (1913), *33*, 1914: 13–19, figs. 25–46 (spawn., Beaufort, North Carolina; develop. of eggs and larvae); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40* (1), 1925: 124 (descr., size, range, Gulf of Maine); Nichols and Breder, Zoologica, N. Y., *9*, 1927: 44 (diagn., range, Orient, New York; life hist. notes).

Anchoviella mitchilli Jordan and Seale (in part; not of Cuvier and Valenciennes), Bull. Mus. comp. Zool. Harv., *67* (11), 1926: 405 (synon., includ. *Engraulis duodecim* Cope; descr., range; Brazilian and West Indian specimens not this species); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43* (1), 1928: 109 (synon., descr., food, spawn., eggs descr., size, abund., habitat, Chesapeake Bay); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 71 (genl.); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 43 (descr., range); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 48 (synon., includ. *Engraulis duodecim* Cope; range); Hildebrand and Cable, Bull. U. S. Bur. Fish., *46*, 1930: 388 (econ. import., spawn., Beaufort, North Carolina; develop. of eggs and young cf. *A. hepsetus*; distinguish. characters this species and *A. hepsetus*; growth rate); Perlmutter, 28th Rep. N. Y. Conserv. Dept.

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[6] Said to have been described and figured by LeSueur, but since no reference to *E. louisiana* LeSueur is given and since none can now be found, the name presumably was taken from a manuscript, and Hildebrand, in his review of the American Engraulidae regarded it as having no standing in modern nomenclature (*3*).

(1938), Suppl., 15 (2), 1939: 18 (around Long Island, New York; spawn.); Greeley, 28th Rep. N. Y. Conserv. Dept. (1938), Suppl., 15 (2), 1939: 83 (Long Island, New York; a forage fish).

Anchoa mitchilli mitchilli Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 87, fig. 37 (synon., descr., cf. *A. mitchilli diaphana*, range).

Anchoa mitchilli diaphana Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 91, fig. 38 (orig. descr. of subspecies *A. m. diaphana*; relation., range); Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 33 (depth, temp., salinity, season, spawn., growth, Texas coast).

Negative References:

Stolephorus mitchilli Bean, Bull. U. S. Fish Comm. (1888), *12*, 1890: 206 (many at Cozumel Island, Yucatán; USNM 37053, 37105 are A. *cayorum*); Schreiner and Miranda-Ribeiro, Arch. Mus. nac., Rio de J., *12*, 1903: 93 (Rio de Janeiro, where this species does not occur).

Anchoviella mitchilli Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 135 (refs. Brazilian recs., where this species does not occur).

Anchovia mitchilli von Ihering, Rev. Industr. Anim., Anno 1 (3), 1930: 232 (Brazil, where the species does not occur).

Anchoa parva (Meek and Hildebrand) 1923

Manjúa (Cuba)

Figure 33

Study Material. At least 34 specimens, 35–60 mm TL, and many more used for some measurements and counts, from the following localities: many from Jamaica; two from Cuba; many from Colón and Porto Bello, Panama, and from Gatun Locks, Canal Zone; one from Laguna de Tacarigua, Venezuela; and one from Trinidad; in USNM, MCZ, UMMZ, BOC, Museo Poey collections.

Distinctive Characters. A. parva is rather close to both subspecies of *mitchilli*, differing principally in having fewer anal rays and more numerous gill rakers, though there is slight overlapping in each instance (see Tables I, II, and III), in the smaller anal fin (see *Description*), in the origin of the anal, which is somewhat farther back under the base of the dorsal, and in the more strongly projecting snout (Figs. 31–33). For the relationship of *parva* to *januaria*, see p. 183. Its closest relative is *curta* of the Pacific coast of Central and South America, from which it is scarcely more than subspecifically distinct (*3*: 84).

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 34 specimens in *Study Material*, 35–60 mm TL.

Body: depth 20–22.
Head: length 23.3–27.8.
Snout: length 4.0–5.5.
Eye: diameter 6.9–9.5.
Postorbital: distance 11.1–14.3.
Maxillary: length 17.3–21.7.
Mandible: length 15–19.
Anal fin: length of base 21–25.
Pectoral fin: length 14.3–17.4.

Scales: *ca.* 38–42.
Gill rakers: 18–20+23–27.
Fin rays: dorsal 13–16; anal 21–23 (rarely as many as 25); pectoral 12 or 13.
Vertebrae: 38–40, rarely 41 (61 specimens).

Body moderately deep, strongly compressed, its depth 4.5–5.0 in SL. Head 3.6–4.3, its depth usually equal to its length without snout. Snout 4.5–6.0 in head, extending about half of its length beyond mandible. Eye 3.0–3.5. Postorbital 1.8–2.3 in head. Maxillary pointed, reaching to margin of opercle, 1.2–1.6 in head. Mandible 1.4–1.75. Cheek scarcely longer than eye, its posterior angle about 60°.

Dorsal fin with the longest rays failing to reach tip of last ray if deflexed, its origin generally equidistant between base of caudal and about middle of eye. Anal with origin under, or more frequently slightly anterior to, middle of dorsal base, its base 4.0–4.8 in SL. Pelvic reaching scarcely halfway to anal, inserted about equidistant between origin of anal and base of pectoral. Pectoral rather variable in length, usually failing to reach pelvic by diameter of pupil, 1.5–1.7 in head. Axillary scale of pectoral generally reaching to beginning of distal third of fin, 2.3–3.0 in head.

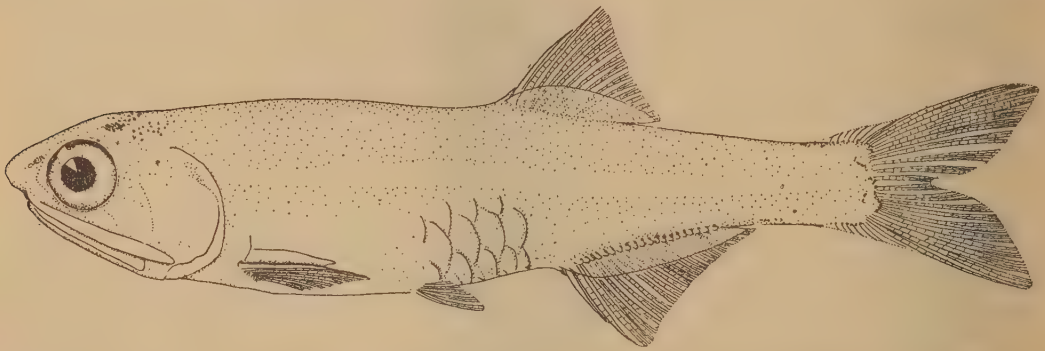

Figure 33. *Anchoa parva*, paratype, 59 mm TL, from Fox Bay, Colón, Panama, USNM 79554. Drawn by Louella E. Cable.

Color. In alcohol, very pale (presumably preserved originally in formalin). Silvery lateral band scarcely as wide as pupil (indistinct or missing in some specimens). Back with dusky punctulations, at least posterior to dorsal fin and extending onto base of upper rays of caudal; larger dark dots usually present at base of anal and continued as a single row onto median line of caudal peduncle.

Size. It is apparently small, as the largest specimen seen is only 60 mm (2.4 in.) TL.

Range and Habitat. Known from the West Indies and the Atlantic coast of Panama and Venezuela. Records of *A. mitchilli* for the West Indies, in part at least, are referable to this species. This fish inhabits salt and brackish water, and fresh water at least to a limited extent. It was very numerous in all three flights of Gatun Locks, Canal Zone, in 1935. The water in the lowermost flight was quite salty, that in the middle one brackish, and that in the uppermost flight, fresh. It has been reported also as occurring in fresh water in Venezuela.

Synonyms and References:

Anchovia parva Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 202, pl. 10, fig. 2 (orig. descr.; type local. Porto Bello, Panama; type USNM 81767; also recorded from Colón); Hildebrand, Zoologica,

N. Y., *24* (1), 1939: 25, 35 (numerous in Gatun Locks, Canal Zone; erroneously reported from Miraflores Locks, Canal Zone, which is *A. curta*).

Anchoviella mitchilli Jordan and Seale (in part; not of Cuvier and Valenciennes), Bull. Mus. comp. Zool. Harv., *67*, 1926: 405 (part of Cuban specimens, *A. parva*).

Anchoviella parva Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (ref. to orig. descr.).

Anchoa parva Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 83, fig. 35 (refs., descr., relation., range); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 43 (synon.; Venezuela; notes, counts).

Doubtful Reference:

Anchoviella parva Fowler, Proc. Acad. nat. Sci. Philad., *83*, 1931: 392 (98-mm specimen from Trinidad much larger than any seen by me; also anal rays more numerous).

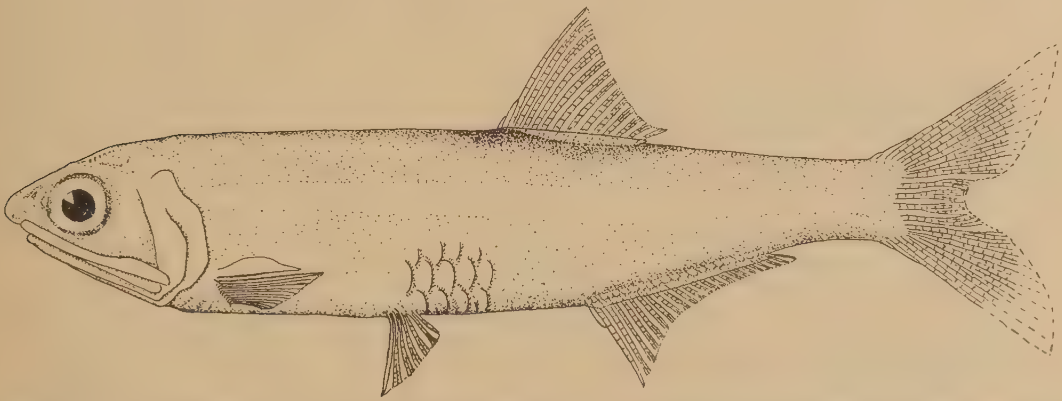

FIGURE 34. *Anchoa januaria*, 75 mm TL, from Pernambuco, Brazil, MCZ 18012. Drawn by Alice C. Mullen.

Anchoa januaria (Steindachner) 1879

Figure 34

Study Material. A total of 28 specimens, 30–75 mm TL, from Amuay[7] and Salinas bays, Gulf of Venezuela; Pernambuco (Recife), Natal, and Rio de Janeiro, Brazil; in USNM and MCZ collections.

Distinctive Characters. From both subspecies of *mitchilli*, *januaria* differs in a somewhat greater number of gill rakers, fewer anal rays, the more posterior position of the anal fin, and the more strongly projecting snout. Compared to both *mitchilli* and *parva*, it has a shorter and blunter maxillary; and from *parva* it differs further in having more numerous gill rakers on the upper limb and in the slightly more posterior position of the anal fin. It differs from *pectoralis* in having fewer pectoral and anal rays and in the more numerous gill rakers.

[7] Schultz (*19*: 44) has claimed that the somewhat mutilated specimens from Amuay Bay, Gulf of Venezuela, identified by me as this species, are *A. blackburni*.

Description. Proportional dimensions in per cent of standard length, and counts, based on 15 or more specimens from 33 mm SL upward.

Body: depth 18–20.
Head: length 22–26.2.
Snout: length 4.15–5.7.
Eye: diameter 6.9–8.0.
Postorbital: distance 10.5–14.2.
Maxillary: length 16.4–19.3.
Mandible: length 15.3–17.

Anal fin: length of base 22–26.
Pectoral fin: length 15.6–17.5.

Scales: *ca.* 36–40.
Gill rakers: 20–23+23–26.
Fin rays: dorsal 14 or 15; anal 21–24; pectoral 12 or 13.
Vertebrae: 41 or 42 (3 specimens).

BODY strongly compressed, its depth 4.3–5.0 in SL. HEAD short, 3.8–4.5 in SL, its depth equal to its length without snout. SNOUT 5.0–6.0 in head, projecting fully half of its length beyond mandible. EYE 2.9–3.6 in head. POSTORBITAL 2.0–2.3 in head. MAXILLARY rather bluntly pointed, its upper margin somewhat rounded, reaching to, or slightly beyond, joint of mandible, 1.3–1.5 in head. MANDIBLE 1.4–1.55. CHEEK about as long as eye, its posterior angle about 50°.

DORSAL fin with its longest rays failing to reach tip of last ray if deflexed, its origin equidistant between base of caudal and about middle of eye. ANAL low, its origin under or slightly posterior to middle of dorsal base, its base scarcely shorter than head, 3.8–4.5 in SL. PELVIC very small, reaching much less than halfway to anal, inserted about equidistant between origin of anal and base of pectoral. PECTORAL small, failing to reach ventral by more than half of diameter of eye, 1.4–2.0 in head. AXILLARY SCALE of pectoral about 75% of length of fin, 2.4 in head.

Color. In alcohol, pale silvery. Silvery lateral band distinct, about 0.5–0.66 of width of eye. Back with dark punctulations, arranged in two rows in some specimens, probably faded in others.

Size. So far as known, this Anchovy reaches a length of only about 75 mm (3 in.).

Range. It apparently ranges from the Gulf of Venezuela to Rio de Janeiro, Brazil.

Synonyms and References:

Engraulis januarius Steindachner, Ichthyol. Beitr., 8, 1879: 58 (orig. descr.; type local. Rio de Janeiro, Brazil; cf. *E. mitchilli*).

Anchovia januaria Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 9 (Natal, Brazil).

Anchoviella januaria Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 206 (descr., Rio de Janeiro, Brazil, and "Brazil"); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (refs. to Brazilian recs.).

Anchoviella mitchilli Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 405 (Pernambuco, Brazil; MCZ 18012 are *A. januaria*).

Anchoa januaria Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 81, fig. 34 (synon., descr., range; cf. *mitchilli*, *parva*, and *pectoralis*).

Anchoa choerostoma (Goode) 1874

Figure 35

Study Material. Many specimens in nine collections from Bermuda.

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 22 specimens, 55–75 mm TL.

Body: depth 18.2–20.8.
Head: length 27.8–30.2.
Snout: length 5.1–6.4.
Eye: diameter 6.5–8.4.
Postorbital: distance 13.3–15.9.
Maxillary: length 21.2–24.3.
Mandible: length 19.2–22.

Anal fin: length of base 20–22.6.
Pectoral fin: length 15.6–18.5.

Scales: *ca.* 38–40.
Gill rakers: 17–20+23–26.
Fin rays: dorsal 13–15; anal 22–24 (rarely 21 or 25); pectoral 12–14.
Vertebrae: 41 or 42 (2 specimens).

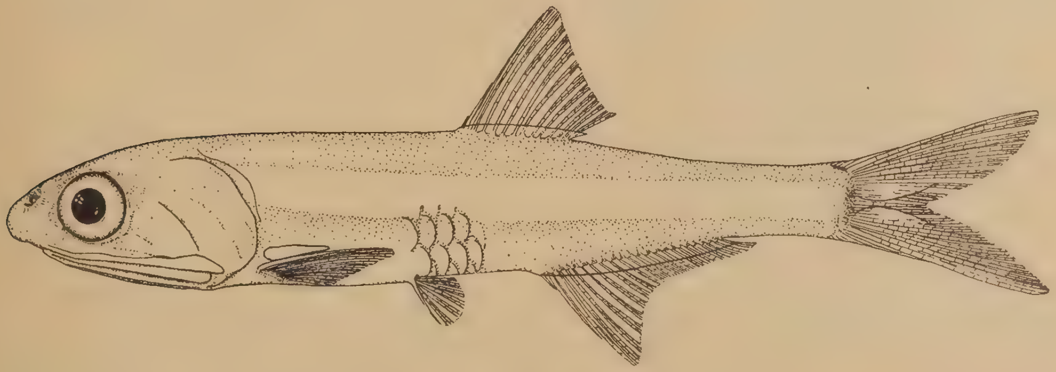

FIGURE 35. *Anchoa choerostoma*, 68 mm TL, from Bermuda, USNM 21976. Drawn by Louella E. Cable.

BODY strongly compressed, moderately deep, its depth 4.8–5.8 in SL. HEAD 3.3–3.6 in SL, its depth equal to postorbital and about half of eye. SNOUT short, projecting rather more than half of its length beyond mandible, 4.7–5.8 in head. EYE 3.3–4.2. POSTORBITAL 1.85–2.1 in head. MAXILLARY reaching nearly to gill opening, not sharply pointed, its upper margin rounded, 1.2–1.3 in head. MANDIBLE 1.3–1.5 in head. CHEEK length equal to eye and fully 75% of snout, its posterior angle about 30°.

DORSAL fin rather high anteriorly, its longest rays reaching to or beyond tip of last ray if deflexed, its origin about equidistant between base of caudal and anterior margin of eye. ANAL with origin somewhere under posterior half of dorsal, but well in advance of the base of last ray, its base 4.4–5.0 in SL. PELVIC failing to reach anal by nearly an eye's diameter, inserted a little nearer to origin of anal than to pectoral base. PECTORAL moderately long, reaching nearly or quite to pelvic, 1.5–1.9 in head.

AXILLARY SCALE of pectoral reaching somewhat beyond midlength of fin, 3.0–4.0 in head.

Color. In alcohol, generally pale. Side with a silvery band (often missing in specimens preserved a long time in formalin), about 75 % of width of eye. Upper surface of head and back with dusky dots, usually arranged in two longitudinal series posterior to dorsal fin.

Size. The largest seen is 75 mm (3 in.) TL, which may be near the maximum size attained.

Reproduction. Specimens taken on June 24, 1927 at Nonsuch, Bermuda contain well developed eggs, indicating that at least some reproduction takes place there during the early part of summer.

Range and Habitat. The range seems to be limited to Bermuda, where no other species of anchovy has been found. West Indian and Panamanian (Atlantic) records are mostly referable to *A. lyolepis.* The collections studied, according to the information furnished, were either seined near shore or taken at night under an electric light. This species has been reported as fairly common about Bermuda (numerous in Hamilton Harbor). Although it has been reported as not at all common during July, it was abundant in August when seined for bait in Bailey's Bay and Flatts Inlet.

Synonyms and References:

Engraulis choerostoma Goode, Amer. J. Sci., *8*, 1874: 125 (orig. descr.; type local. Bermuda; types lost); Ann. Mag. nat. Hist., (4) *14*, 1874: 380 (as in Goode, 1874).

Stolephorus choerostoma Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 444 (descr. after Goode; ref.); Barbour, Bull. Mus. comp. Zool. Harv., *46*, 1905: 113 (abund. in Bermuda; distrib., includ. Puerto Rico, where it apparently does not occur; refs.); Bean, T. H., Field Mus. Publ., Zool., *7*, 1906: 34 (several locals in Bermuda).

Anchoviella choerostoma Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 48 (ref., Hamilton Harbor, Bermuda); Fowler, Proc. biol. Soc. Wash., *43*, 1930: 146 (72 from Bermuda).

Anchoa choerostoma Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 71, fig. 28 (refs., descr., distrib.).

Negative References:

Anchoviella choerostoma Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 404 (not *A. choerostoma* [Goode]; descr. evidently based on *A. lyolepis* [Evermann and Marsh]; those from Puerto Rico and e. coast of Panama are *lyolepis*); Beebe and Tee-Van, Field Bk. Shore Fish. Bermuda, 1933: 38, fig. (not *A. choerostoma* [Goode]; fig. and descr. at least in part from Beebe and Tee-Van [1928: 47]; distrib. includ. West Indies, where this species apparently does not occur); Beebe and Tee-Van, Zoologica, N. Y., *13* (7), 1933: 136 (*A. choerostoma* var. *atlantica* Borodin [1928: 7] from e. coast of Panama put in synon., but *A. choerostoma* [Goode] apparently does not occur there. Borodin's fish not ident. from his descr.).

Anchoa tricolor (Agassiz) 1829

Piquitinga

Figure 36

Study Material. Many specimens, from: Gulf of Venezuela (1); Natal (8), Rio de Janeiro (52), São Francisco (5), and Sambara River (20), Brazil; Montevideo, Uruguay

(1); and Puerto de (or Rio) Quequen, Mar del Plata, Argentina (2), in USNM, MCZ, CNHM, MHNBA, UMMZ, SU collections.

Distinctive Characters. This species generally has been identified in museum collections with *brownii* = *hepsetus*, which it resembles in size and general appearance, but it differs sharply from it in the shorter and differently shaped maxillary and in the more numerous gill rakers (Tables II and III).

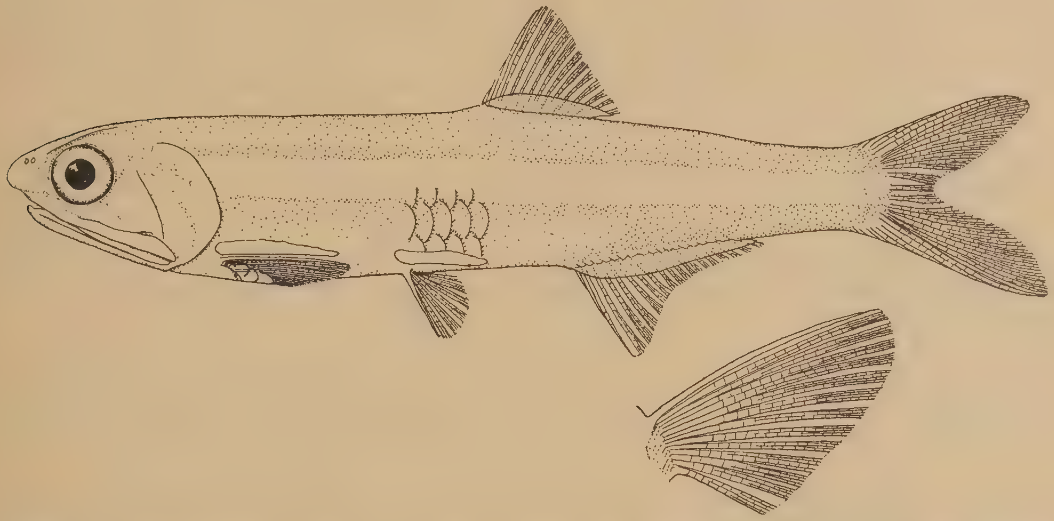

FIGURE 36. *Anchoa tricolor*, 110 mm TL, 91 mm SL, from Rio de Janeiro, Brazil, USNM 87721, with pectoral fin enlarged. Drawn by Louella E. Cable.

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 41 specimens, 63–118 mm TL.

Body: depth 18.2–21.
Head: length 23.8–26.7.
Snout: length 4.15–5.9.
Eye: diameter 6.7–8.1.
Postorbital: distance 12.5–13.5.
Maxillary: length 18.2–21.5.
Mandible: length 15.6–18.3.

Anal fin: length of base 17.2–20.
Pectoral fin: length 14–14.8.

Scales: *ca.* 42–45.
Gill rakers: 18–22 + 24–28.
Fin rays: dorsal 14–16; anal 18–22; pectoral 13–15.
Vertebrae: 40–42 (5 specimens).

BODY quite slender, moderately compressed, its depth 4.75–5.5 in SL. HEAD 3.75–4.2 in SL, its depth equal to its postorbital length and fully half of eye. SNOUT projecting about half of its length beyond mandible, 4.75–5.8 in head. EYE 3.25–3.75. POSTORBITAL 1.85–2.15 in head. MAXILLARY not sharply pointed, its upper margin rounded, reaching to, or a little beyond, joint of mandible, 1.3–1.4 in head. MANDIBLE 1.3–1.5. CHEEK rather broad, scarcely longer than eye, its posterior angle about 55°.

Dorsal fin with longest rays failing to reach tip of last ray if deflexed, its origin about equidistant between base of caudal and middle of eye. Anal with origin somewhere under posterior fourth of dorsal, its base 5.0–5.8 in SL. Pelvic reaching scarcely halfway to anal, inserted about equidistant between origin of anal and pectoral base. Pectoral scarcely falcate, failing to reach pelvic by diameter of pupil to 75% of diameter of eye, 1.75–2.0 in head. Axillary scale of pectoral often shorter than fin by diameter of pupil, 1.9–2.75 in head.

Color. In alcohol, generally rather pale. Side of head silvery. Lateral band bright silvery, about 75% of width of eye.

Size. The largest measured is 118 mm (4.7 in.) TL, which may be near the maximum length attained.

Commercial Importance. Most of the specimens examined were obtained in markets, indicating that this Anchovy has at least some direct economic value to man.

Range. The range, so far as known, extends from the Gulf of Venezuela to Mar del Plata, Argentina, but it apparently does not include streams. This Anchovy's frequent appearance in the Rio de Janeiro market (Brazil) seems to indicate that it is common locally.

Synonyms and References:

Engraulis tricolor Agassiz, in Spix and Agassiz, Pisc. Brasil., 1829: 51, tab. 23, fig. 1 (orig. descr.; type local. Bahia, Brazil; plate labeled *Engraulis piquitinga*); Goeldi, Boll. Museu Paraense, *2* (3), 1898: 466 (names; from type local.).

Stolephorus brownii Jordan and Evermann, Bull. U. S. nat. Mus., *47* (1), 1896: 443 (descr., range, synon., includ. *E. tricolor* Agassiz).

Anchovia brownii Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 10 (Natal, Brazil; local abund.; descr. *tricolor* by my exam.).

Anchoviella salvatoris Fowler and Bean, Proc. U. S. nat. Mus., *63* (19), 1923: 6 (orig. descr.; type local. Rio de Janeiro, Brazil; type USNM 83165, in bad condition, apparently *tricolor*); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (refs.).

Anchoviella epsetus Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 396 (Rio de J. and "Sambaia" [probably Sambara R.], Brazil; Montevideo, Uruguay; all exam. and are *tricolor*); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 48 (includ. *tricolor*); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (refs. to Brazilian recs., in part *tricolor*).

Anchoviella bonaiensis Marini, Physis, Rev. Soc. Argent. Cienc. nat., *11*, 1935: 446 (NOMEN NUDUM; type local. Mar del Plata, Argentina; type in MHNBA; exam. by me and found to be *tricolor*).

Anchoa tricolor Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 74, fig. 30 (synon., descr., relation., distrib.); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 43 (synon.).

Anchoa cubana (Poey) 1868

Cuban Anchovy, Bocón, Manjúa (Cuba)

Figure 37

Study Material. A total of 39 specimens, 45–70 mm TL, including two from Poey's type material, MCZ 17958, and two paratypes of *Stolephorus astilbe* Jordan and Rutter, MCZ 31392; many more for the gill raker counts; from Melbourne Beach and Marco, Florida; Mobile Bay, Alabama; off Grand Isle, Louisiana; Progreso, Yucatán, México; Puerto Barrios, Guatemala; Cuba; Jamaica; and St. Thomas.

Distinctive Characters. This species differs from *A. hepsetus* and from nearly all other local forms in a very slender body and more numerous gill rakers.

Description. Proportional dimensions in per cent of standard length, and counts, based on 39 specimens, 45–70 mm TL.

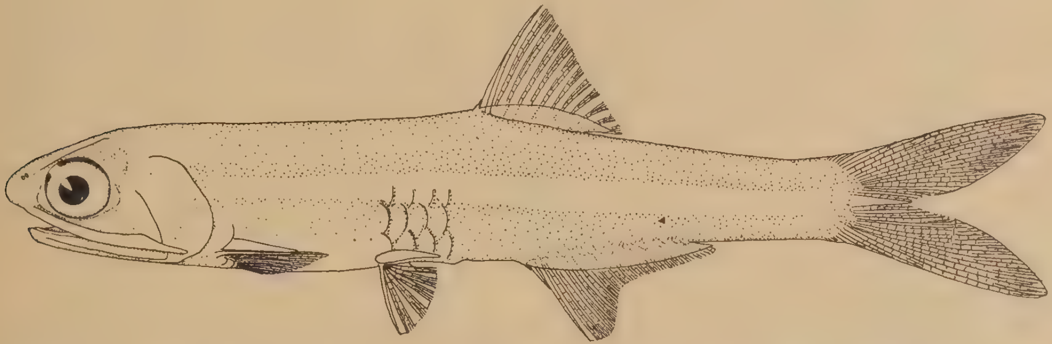

FIGURE 37. *Anchoa cubana*, 63 mm TL, 53 mm SL, from St. Thomas, West Indies, USNM 83802. Drawn by Louella E. Cable.

Body: depth 15–18.
Head: length 22.7–27.8.
Snout: length 3.85–4.7.
Eye: diameter 6.1–7.75.
Postorbital: distance 10.5–12.5.
Maxillary: length 18.7–22.2.
Mandible: length 15.6–18.8.
Anal fin: length of base 18.5–22.2.
Pectoral fin: length 12.5–13.7.

Scales: *ca.* 40–43.
Gill rakers: 17–23+23–33, usually 19–22+25–28 (Tables II, III).
Fin rays: dorsal 14–16; anal 20–24; pectoral 13 or 14.
Vertebrae: 42 or 43 (14 specimens).

BODY slender, rather strongly compressed, with a rather sharp edge on chest and abdomen, its depth 5.5–6.7 in SL. HEAD small, 3.6–4.3 in SL, its depth equal to its postorbital length and about a third of eye. SNOUT short, extending about 66% of its length beyond tip of mandible, 4.8–6.5 in head. EYE small, 3.5–4.0. POSTORBITAL short, 1.9–2.3 in head. MAXILLARY bluntly pointed, its upper margin nearly straight, usually extending nearly to margin of opercle, 1.1–1.25 in head. MANDIBLE 1.4–1.75. CHEEK somewhat longer than eye, its posterior angle rather broad, about 45°. GILL RAKERS slender, close-set, often difficult to count (probably accounting for wide range given).

DORSAL fin with the longest rays failing to reach tip of last ray if deflexed, its origin about equidistant between base of caudal and some point over posterior half of eye. ANAL with origin under or slightly in advance of middle of dorsal base, its base 4.5–5.4 in SL. PELVIC reaching somewhat less than halfway to origin of anal, inserted a little nearer to origin of anal than to pectoral base. PECTORAL failing to reach base of pelvic by nearly an eye's diameter, 1.75–1.9 in head. AXILLARY SCALE of pectoral about 75% of length of fin, 2.4–3.0 in head.

Color. In alcohol, rather pale. Side of head silvery. Lateral band bright silvery, about as wide as pupil (often missing in specimens preserved in formalin). Back usually with dusky punctulations not arranged in definite longitudinal series.

Size. The largest fish seen was only 70 mm (2.8 in.) long, and most of the numerous specimens examined were under 65 mm TL.

Range and Habitat. A. cubana ranges from both coasts of Florida, along Alabama and Louisiana, and through the West Indies, to Yucatán, México, and Puerto Barrios, Guatemala. It is also recorded for Puerto Rico (*18*: 344) and Grenada (*1*: 269). It seems to be common around Jamaica, probably also around Cuba, but apparently it is rather rare on our southern coast. The specimens from the West Indies, in part at least, were taken in shallow water, whereas those from the United States were taken with trawls hauled at depths as great as 30 fms.

Synonyms and References:

Engraulis cubanus Poey, Repert. Fisico-Nat. Cuba, *2*, 1868: 420 (orig. descr.; type local. Cuba; MCZ 17958); Poey *in* Gundlach, An. Soc. esp. Hist. Nat., *10* (4), 1881: 344 (Puerto Rico).

Stolephorus cubanus Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 442 (descr. from orig., range); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 88 (after Jordan and Evermann, 1896).

Stolephorus astilbe Jordan and Rutter, Proc. Acad. nat. Sci. Philad., 1897: 95 (orig. descr.; type local. Kingston, Jamaica; type SU 4854; paratypes MCZ 31392); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (3), 1898: 2815 (descr. from orig., synon.).

Anchoviella cubana Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 399 (synon., descr., Cuba, includ. type material, MCZ 17958); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 48 (synon., range); Fowler, Proc. Acad. nat. Sci. Philad., *82*, 1930: 269 (Grenada, B.W.I.); Howell-Rivero, Bull. Mus. comp. Zool. Harv., *82*, 1938: 172 (4 specimens in type material, the largest said to be type, MCZ 17958).

Anchoviella astilbe Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 402 (synon., descr., paratypes MCZ 31392); Jordan, Evermann, and Clark, Rept. U. S. Comm. Fish. (1928), 2, 1930: 49 ("West Indies"); Fowler, Proc. Acad. nat. Sci. Philad., *82*, 1930: 269 (Grenada, B.W.I.).

Anchovia cubana Nichols, N. Y. Acad. Sci., *10* (2), 1929: 204 (synon., diagn., Cuba and Puerto Rico).

Anchoa cubana Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 76, fig. 31 (synon., descr., extension of range; cf. paratypes of *cubana* and *astilbe*).

Anchoa ginsburgi Hildebrand 1943

Figure 38

Study Material. Type material, 16 specimens, from juveniles 28 mm long to adults or near adults 63 mm TL, from Gulf of Venezuela.

Distinctive Characters. This species differs from *hepsetus* chiefly in the shorter and blunter maxillary and in the more numerous vertebrae when compared with *hepsetus* from southern localities, especially from Yucatán and Panama (*3*: 56, tab. 7). Among specimens of equal size, this species seems to be more slender.

Description. Proportional dimensions in per cent of standard length, and counts, based on 13 specimens, 43–63 mm TL.

Body: depth 17.4–18.8.
Head: length 25–28.5.
Snout: length 4.9–5.9.
Eye: diameter 6.6–9.1.
Postorbital: distance 14.5–15.8.
Maxillary: length 17.2–18.2.
Mandible: length 15.5–17.8.

Anal fin: length of base 19.2–22.
Pectoral fin: length 13.7–15.3.

Scales: *ca.* 42–45.
Gill rakers: 16–18+20–22.
Fin rays: dorsal 14 or 15; anal 18–20; pectoral 13–15.
Vertebrae: 44 or 45 (2 specimens).

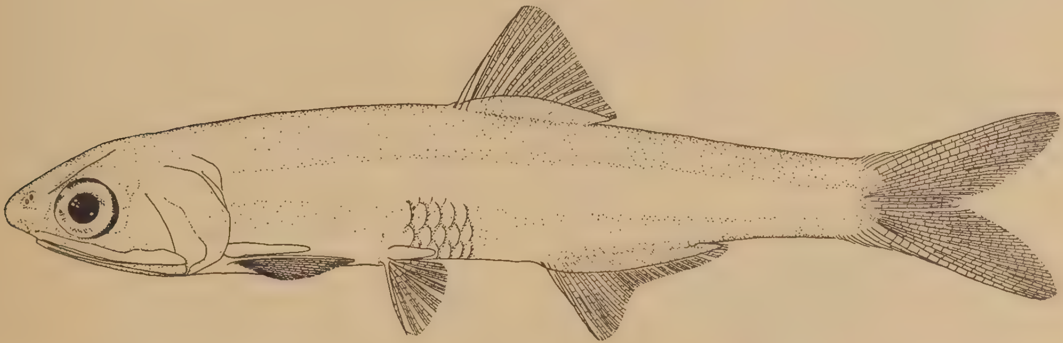

FIGURE 38. *Anchoa ginsburgi*, paratype, 60 mm TL, 52 mm SL, from Gulf of Venezuela, USNM 119789. Drawn by Louella E. Cable.

BODY slender, moderately compressed, its depth 5.3–5.75 in SL. HEAD 3.5–4.0 in SL, its depth equal to its postorbital length and about half of eye. SNOUT short, projecting a little more than half of its length beyond mandible, 4.5–5.25 in head. EYE 3.25–4.0. POSTORBITAL moderately long, 1.3–1.9 in head. MAXILLARY short, its upper margin rounded, reaching joint of mandible, 1.3–1.5 in head. MANDIBLE 1.5–1.65. CHEEK broad, a little longer than eye, its posterior angle about 45°.

DORSAL fin low, the longest rays failing to reach tip of last ray if deflexed, its origin usually somewhat nearer to base of caudal than to anterior margin of eye. ANAL short, with origin commonly slightly posterior to middle of dorsal, its base 4.5–5.2 in SL. PELVIC small, inserted equidistant between origin of anal and base of pectoral, or a little nearer to the latter. PECTORAL scarcely falcate, failing to reach pelvic by about half of diameter of eye, 1.7–2.0 in head. AXILLARY SCALE of pectoral moderately pointed, failing to reach tip of fin by about 75% of diameter of eye, 2.8–3.1 in head.

Color. In alcohol pale (originally preserved in formalin). Side of head silvery. Lateral band bright silvery, about 75% of width of eye.

Range. Known only from the holotype and 15 paratypes, all from the Gulf of Venezuela, partly from Estauques Bay and partly from Salinas Bay.

References:

Anchoa ginsburgi Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 55, fig. 20 (orig. descr.; type local. Estauques Bay, Gulf of Venezuela; type USNM 119788); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 43 (ref., types, locals.).

Anchoa lamprotaenia Hildebrand 1943

Longnose Anchovy, Manjúa (Cuba)

Figure 39

Study Material. A total of 80 specimens, 46–92 mm TL, collected at Palm Beach, Miami, Key West, and Tortugas, Florida; Progreso, Yucatán, México; Cuba; Puerto Rico; British Honduras; and the Atlantic coast of Panama.

Distinctive Characters. This species until recently has been consistently identified with *A. hepsetus* in museum collections. Since these species are not easily separated by any one character, a combination of characters is sometimes necessary. Generally *A. lamprotaenia* is distinguished by its longer and more falcate pectoral fin, higher dorsal fin, shorter and broader axillary scale of the pectoral, and by the shorter and more bluntly pointed maxillary with its upper rounded margin. The average number of anal rays is greater and the average number of pectoral rays, gill rakers, and vertebrae is fewer (see *Description* and Tables I–III).

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 46–92 mm TL.

Body: depth 19–23.
Head: length 25–30.
Snout: length 8.1–9.5.
Eye: diameter 7.5–8.3.
Postorbital: distance 14.3–16.
Maxillary: length 21.5–24.5.
Mandible: length 18.5–22.
Anal fin: length of base 20.5–23.5.

Pectoral fin: length 14.3–18.

Scales: *ca.* 38–41.
Gill rakers: 13–18+16–20 (usually 14 or 15+18 or 19).
Fin rays: dorsal 13–15; anal 19–26 (usually 21–24); pectoral 11–15 (most frequently 12 or 13).
Vertebrae: 39–42 (98 specimens).

Body strongly compressed, its greatest thickness about equal to depth of caudal peduncle, its depth 4.3–5.25 in SL. Head 3.3–4.0, its depth about equal to its postorbital length and half of eye. Snout pointed, projecting about 66% of its length beyond tip of mandible, 4.5–5.75 in head. Eye 3.5–4.0 in head. Postorbital 1.75–2.0 in head. Maxillary not sharply pointed, usually distinctly rounded above, reaching to, or more usually somewhat beyond, joint of mandible, 1.2–1.4 in head. Mandible 1.35–1.6 in head. Cheek as long as eye and fully half of snout, its posterior angle about 35°. Gill rakers about 75% of length of eye.

Dorsal fin rather high anteriorly, its longest rays usually reaching beyond tip of last ray if deflexed, its origin equidistant between some point over snout or anterior half of eye and base of caudal. Anal fin with origin under or near beginning of posterior third of dorsal base, its base 4.25–4.9 in SL. Pelvic usually inserted slightly nearer to origin of anal than to base of pectoral. Pectoral long, falcate, usually failing to reach pelvic by only diameter of pupil, its longest ray in a few specimens with a slight filament, the rays decreasing rapidly in length after the third one, the shortest ray scarcely reaching past midlength of first (uppermost) one, 1.5–1.9 in head. Axillary scale of pectoral broad at base, scarcely reaching beyond midlength of fin, 3.0–3.6 in head.

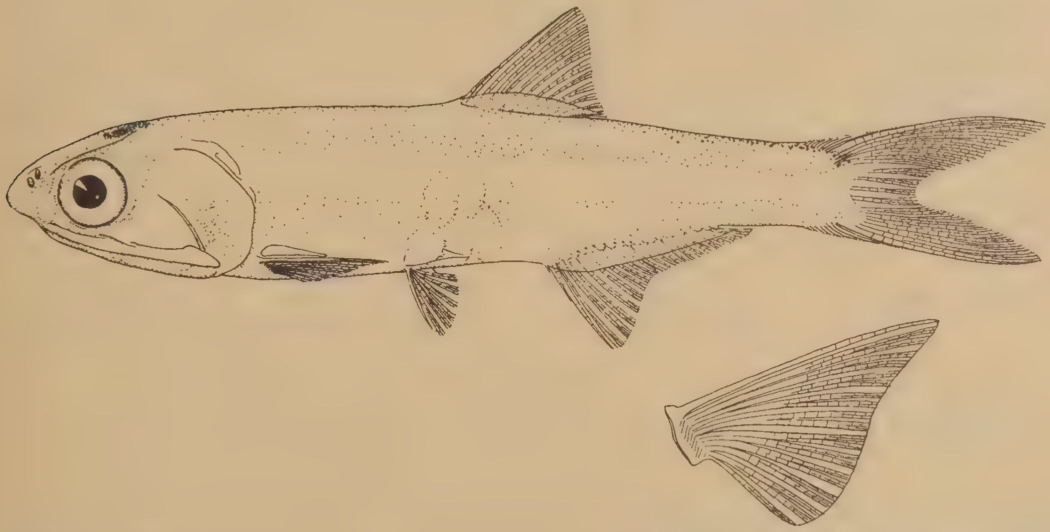

Figure 39. *Anchoa lamprotaenia*, paratype, 60 mm TL, 48 mm SL, from Key West, Florida, USNM 35000, with pectoral fin enlarged. Drawn by Louella E. Cable.

Color. Preserved specimens pale. Side of head bright silvery. Silvery lateral band prominent, not quite as wide as eye. Punctulations on back not prominent; a few dark dots at base of anal; dorsal and caudal with a few dusky points; other fins unmarked.

Size. A. lamprotaenia apparently attains a smaller size than *A. hepsetus*, the largest seen being only 92 mm (3.7 in.) TL.

Reproduction. Specimens taken at Key West, Florida, June 11, 1936, and at Bush Key (Tortugas), Florida, July 23, 1937, contained well-developed roe, showing that at least some spawning takes place in southern Florida during midsummer.

Range and Habitat. From southern Florida through the West Indies to Panama, and probably to northern Brazil as shown by an imperfect specimen. The collections studied were apparently taken in shallow water near shore. The species is common in the Florida Keys, where *A. hepsetus* seems to be very rare.

Synonyms and References:

Stolephorus brownii Jordan, Proc. U. S. nat. Mus., 7, 1885: 106 (abund. at Key West, Florida; specimens USNM 35000 are *A. lamprotaenia*); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 88 (descr., range, distr. in Puerto Rico; synon.; specimens from Fajardo [USNM 73755], at least, are *A. lamprotaenia*).

Anchovia brownii Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 204, pl. 14, fig. 1 (synon., descr., range, specimens from Colón [CNHM 8217] and Porto Bello [CNHM 8216], Panama, in part are *A. lamprotaenia*).

Anchoviella epsetus Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 396 (synon., descr., range; specimens from Tortugas [MCZ 17944] and Key West [MCZ 18035], Florida, are *A. lamprotaenia*); Pierce, Copeia, 1936: 123 (sample of specimens used in feed. experiments are *A. lamprotaenia*); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 12 (notes on structure; distr. at Tortugas, Florida; specimens preserved are *A. lamprotaenia*).

Anchoa lamprotaenia Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 62, fig. 23 (orig. descr.; type local. Key West, Florida; type USNM 117661; range cf. *A. hepsetus*).

Doubtful References:

Anchovia brownii Jordan and Thompson, Bull. U. S. Bur. Fish. (1904), 24, 1905: 233 (Garden Key [Tortugas], Florida; probably part, if not all, are *lamprotaenia*); Fowler, Proc. Acad. nat. Sci. Philad., *58*, 1906: 84; and *63*, 1911: 216 (from several Florida Keys; probably part, if not all, are *lamprotaenia*).

Anchoa hepsetus (Linnaeus) 1758

Striped Anchovy (U.S.), Manjúa (Cuba)

Figures 40, 41

Study Material. At least 83 specimens, 55–140 mm TL, and many more, taken at various places from New Jersey southward to Uruguay.

Distinctive Characters. A. hepsetus is related closely enough to *A. lamprotaenia* so that they are not always separable by any one character, a combination of characters sometimes being necessary. In general, *hepsetus* has a shorter and less falcate pectoral fin, a lower dorsal fin, a longer and narrower axillary scale on the pectoral, and a rather longer and more sharply pointed maxillary. Also, its average number of anal rays is lower, and its average number of pectoral rays, gill rakers, and vertebrae is higher. It is related also to *A. ginsburgi*, from which it differs especially in the longer and more sharply pointed maxillary, and generally in having fewer vertebrae.

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 83 specimens, 55–140 mm TL.

Body: depth 18.5–22.
Head: length 25–30.
Snout: length 4.4–6.3.
Eye: diameter 7.15–8.7.
Postorbital: distance 13.5–15.5.
Maxillary: length 19–24.5.
Mandible: length 16.5–20.
Anal fin: length of base 19–22.5.
Pectoral fin: length 14.5–17.5.
Scales: *ca.* 37–43.
Gill rakers: 15–20+18–24 (usually 16–19+19–22).
Fin rays: dorsal 13–16; anal 18–23; pectoral 13–15 (most frequently 14 or 15).
Vertebrae: 40–44 (399 specimens), decreasing somewhat in number southward at least to Panama.

BODY slender, moderately compressed, its greatest thickness generally exceeding the depth of caudal peduncle, its depth 4.5–5.4 in SL. HEAD 3.3–4.0 in SL, its depth equal to postorbital and about a fourth of eye. SNOUT projecting about 66% of its length beyond tip of mandible, 4.5–6.0 in head. EYE 3.25–4.0 in head. POSTORBITAL 1.8–2.1 in head. MAXILLARY quite pointed, its upper free margin generally straight, reaching nearly to margin of opercle, 1.2–1.3 in head. MANDIBLE 1.4–1.6 in head. CHEEK a little longer than eye, its posterior angle rather broad, about 45°. GILL RAKERS at angle of first arch about 75% of length of eye.

DORSAL fin low, its margin somewhat concave, its longest rays failing to reach tip of last ray if deflexed, its origin usually about equidistant between base of caudal and middle of eye. ANAL fin with origin under middle to posterior fourth of dorsal base, its base 4.4–5.2 in SL. PELVIC reaching about halfway to origin of anal, inserted nearly equidistant between origin of anal and pectoral base. PECTORAL not strongly falcate, its four uppermost rays usually of about equal length, its first or uppermost one sometimes a little shorter than the second one, its last or shortest ray usually reaching well past midlength of the first one, the fin often failing to reach base of pelvic by diameter of eye, though sometimes nearly reaching it, its length 1.7–2.0 in head. AXILLARY SCALE of pectoral slender, usually failing to reach tip of fin by less than diameter of pupil, 2.0–2.5 in head.

Color. Preserved specimens, pale above. Lower parts pale silvery. Side of head silvery. Middle of side with a bright silvery band, variable in width, often about 75% of width of eye above base of anal, sometimes scarcely wider than pupil.

Size. The largest specimen seen, from Beaufort, North Carolina, is 153 mm (6.1 in.) TL, which probably is near the maximum size attained. A specimen 150 mm long, weighing one ounce, has been reported for Chesapeake Bay. The usual size ranges between about 100–125 mm TL.

Development and Growth. The egg is elliptical, with a major axis of about 1.4–1.6 mm and a minor one of about 0.7–0.85 mm. It is transparent and has no oil globule. The yolk, as in other anchovies studied, is separated into masses having the appearance of large cells under magnification. The egg floats at or near the surface and hatches within about 48 hours at a water temperature of about 66°–70° F.

The newly hatched fish, very slender and thread-like, is about 3.6–4.0 mm long. It is transparent, has a slight greenish shade on the head, and has no definite chromatophores; the head is slightly concave. The myomeres are very distinct. It is quite active. The yolksac generally is absorbed within 24 hours after hatching at 65°–70° F. The fish is then about 4.0–4.5 mm long, at which stage the mouth is open and apparently functional. The fish is still transparent.

The first chromatophores, situated in the midventral line of the chest, appear when the fish is about 5.0 mm long, and at this stage the mouth is large, terminal, and oblique. The dorsal and anal fins become more or less definitely differentiated at a length of 5.0–6.0 mm, but the rays cannot be counted accurately until the fish is about 10 mm, at which length it has become considerably more robust, the notochord is definitely bent upward in the base of the caudal fin, and the caudal has indefinite rays.

At a length of 15 mm the caudal fin is well developed and forked, the notochord is no longer visible, and the mouth remains terminal and oblique. Some additional chromatophores have appeared along the ventral surface, and dark pigment has appeared along the upper margin of the eye.

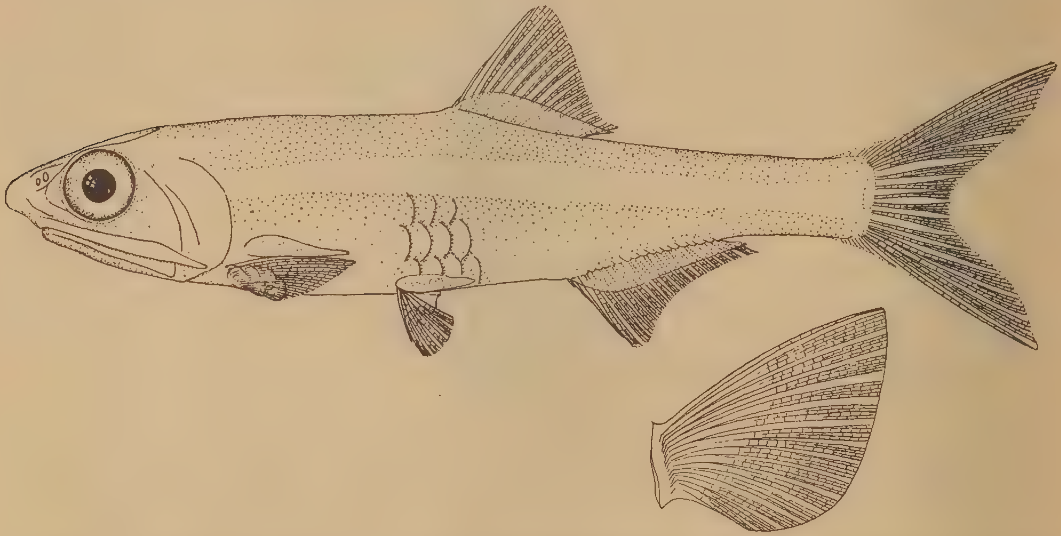

FIGURE 40. *Anchoa hepsetus hepsetus*, 114 mm TL, from Atlantic City, New Jersey, USNM 127525, with pectoral fin enlarged. Drawn by Louella E. Cable.

Little external development takes place while the fish grows from a length of 15 to 25 mm. However, when the fish reaches 35 mm, the mouth has become almost horizontal, as in adults, and the conical snout projects prominently. Pigmentation has increased and the silvery lateral band of the adult, though narrow and indistinct at this point, has appeared. Although the body has now become fairly robust, it remains more slender than in adults, its depth being contained in the length about 6.0 times.

When it reaches a length of about 40–45 mm it may be definitely considered a young adult. Although it remains somewhat more slender than larger fish, it is fully pigmented, has the characteristic silvery lateral band well developed, is fully scaled, and is easily identified with the adult (*4*: 389–393; also unpublished field notes of the writer).

Spawning. In the vicinity of Beaufort, North Carolina, spawning begins early in the spring. April 16 is the earliest date on which eggs have been taken. Toward the middle of June, eggs diminished in number in the tows, though a few were taken throughout July. The young, 22 mm and less, were collected in Beaufort Inlet as early as April 11. (*4*: 388; also unpublished data of the writer).

Food. When the fish is about 20 mm the food consists largely of copepods. As the fish grows, this diet is supplemented by gastropods, foraminifera, an occasional ostracod, and annelid worms. The diet of the adult is essentially the same (Linton, *11*: 440; *12*: 353; *4*: 395).

Parasites. The principal parasites are nematodes, cestodes (*Scolex polymorphus* and *Rhynchobothrium* sp.), and trematodes (*Distomum appendiculatum* and *Distomum* sp.) (*11*: 440; *12*: 353).

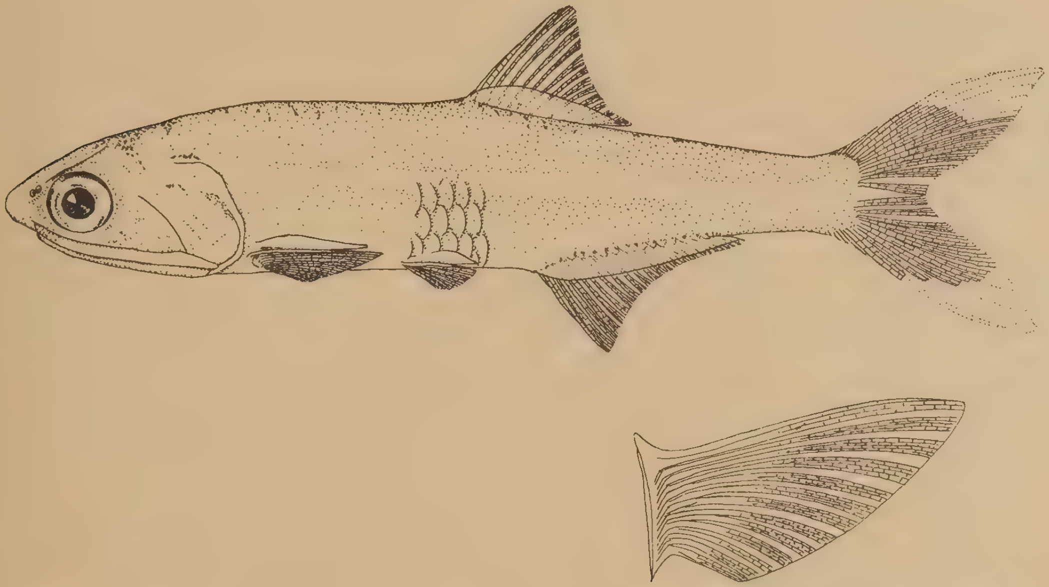

FIGURE 41. *Anchoa hepsetus colonensis*, 70 mm TL, 56 mm SL, from Colón, Panama, USNM 117664, with pectoral fin enlarged. Drawn by Louella E. Cable.

Variation. So great is the variation in this species that certain specimens from Colón, Panama, and northward to the Gulf of Mexico were recognized (*3*: 60, fig. 22) as a subspecies, *A. hepsetus colonensis*. The greatest divergence is apparent in specimens from Colón, Panama, with complete intergradation in specimens on the Gulf coast of the United States. As typical *hepsetus* occurs through the range of *h. colonensis*, the latter is not a geographical variant but one that occurs within the range of the typical species.

The variant, or subspecies *colonensis*, differs from typical *hepsetus* in having a somewhat deeper and more strongly compressed body, its greatest thickness scarcely exceeding the depth of the caudal peduncle. Its pectoral fin is longer and more pointed, generally extending nearly or quite to the base of the pelvic fin. Its silvery lateral band is narrower, often scarcely exceeding the width of the pupil.

Commercial Importance. Each year large quantities are marketed as food for man. In 1939 about 21,000 pounds and in 1940 about 29,000 pounds were handled in the New York City markets. It is economically important, however, chiefly as a forage fish.

It is preyed upon by several commercially important fishes, especially the seatrouts (*Cynoscion*). Water birds also feed on it extensively.

Range. Plentiful from Chesapeake Bay to the West Indies; north irregularly to southern New England and as a stray to Maine and the outer coast of Nova Scotia; south at least as far as Montevideo, Uruguay. It has also been recorded for Cape Verde, Africa, but that record is in need of verification.

In some years it is numerous at Beaufort, North Carolina, appearing in large schools, but in other years less abundant. At Beaufort and in Chesapeake Bay it was taken chiefly with seines near the shore and rarely with trawls in somewhat deeper water; however, in the Gulf of Mexico it was taken in deeper water more commonly. Collections made with otter trawls, some of them in water as much as 30–40 fms. deep, are at hand from off Corpus Christi, Texas, off Grand Isle, Louisiana, and off St. Vincent Island and Apalachicola Bay, Florida.

Details of Occurrence.[8] Stray specimens of this Anchovy were reported for Halifax, Nova Scotia, in 1931 (*21*: 3), and for the mouth of the Penobscot River, Maine, in 1930, when many others were reported as seen (*8*). The next most northerly locality of record is the vicinity of Woods Hole, southern Massachusetts, where it has been reported as abundant, at least in some years. But only one specimen of this particular Anchovy has been reported for Rhode Island. It is less common in New York waters than its relative *mitchilli* (p. 179), but it has been reported as being locally abundant there; this applies equally to New Jersey waters and to Chesapeake Bay as a whole.

Farther to the south, *hepsetus* appears in large schools in some years along the coast of North Carolina (see above), where *mitchilli* has been reported only once (p. 179). It is known from Georgia, the Florida Keys region, various localities along the western coast of Florida from Cape Sable to Pensacola, the coast of Mississippi, Grand Isle and Cameron, Louisiana, Galveston and Mustang Island, Texas, on the Mexican coast off Tampico, Vera Cruz, and Yucatán, and the Atlantic coast of Panama. It is widespread throughout the West Indies also, where it has been recorded for the northern coast of Cuba, St. Thomas, Puerto Rico, Haiti, Santo Domingo, Jamaica, Curaçao, St. Kitts, Martinique, and Barbados. On the coast of Brazil it is known at Mamanguape (near Pernambuco), Bahia, and Rio de Janeiro.

Synonyms and References:

Esox hepsetus Linnaeus, Syst. Nat., ed. 10, 1758: 314 (diagn.; type local. "America"; refs. to 'Piquitinga' Marcgrave, Brazil, and Menidia Browne, Jamaica, nonbinomials).

Atherina epsetus Bonnaterre, Tabl. Encyc. Meth. Ichthyol., 1788: 175 (descr., same fin ray counts as Linnaeus; ref. to Linnaeus, but apparently not ed. 10).

Atherina brownii Gmelin, Syst. Nat., *1*, 1788: 1397 (based on Menidia Browne, pre-Linnaean).

Clupea vittata Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 456 (orig. descr.; type local. New York; type lost); De Kay, New York Fauna, Pt. 4: Fishes, 1842: 254 (descr.); Storer, Mem. Amer. Acad. Arts Sci., 1846: 205, in separate (brief descr., New York).

Engraulis brownii Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 41 (descr., New York, West Indian locals., Vera Cruz, Rio de Janeiro; also several Indian O. locals. where this species does not occur); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 389 (descr., West Indies, Gulf of Mexico, and Bahia; also from "Libertad," Pacific Central America, and Ceylon where the species does not occur; synon. includ. *E. tricolor*, which is a valid species); Poey, Repert. Fisico-Nat. Cuba, *2*, 1868: 419 (descr., Cuba); Poey, Enumerat., Pisc. Cubana, 1875: 149 (relations., Cuba, Jamaica, and San Domingo); Yarrow, Proc. Acad. nat. Sci. Philad., 1877: 215 (Ft. Macon, North Carolina; "not common").

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[8] Added by H. B. Bigelow.

Argentina menidia Gronow, Cat. Fish., 1754: 141 (based on Menidia Browne, pre-Linnaean).

Engraulis vittatus Jordan and Gilbert, Proc. U. S. nat. Mus., *1*, 1879: 385 (common, Beaufort Harbor, North Carolina).

Engraulis hiulcus Goode and Bean, Proc. U. S. nat. Mus., *2*, 1880: 343 (orig. descr.; type local. Clearwater Harbor, Florida; USNM 23632; in bad condition, about 57 mm long, not 47 mm as stated by Goode and Bean).

Stolephorus perthecata Goode and Bean, Proc. U. S. nat. Mus., *5*, 1883: 434 (orig. descr.; type local. Pensacola, Florida; type USNM 30483); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 442 (descr.).

Stolephorus browni Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1883: 273 (descr., range, synon.); Swain, Bull. U. S. Fish Comm. (1882), *2*, 1883: 56 (descr., several locals. between New York and Brazil; synon., includ. *tricolor*); Jordan and Swain, Proc. U. S. nat. Mus., *7*, 1885: 230 (Cedar Keys, Florida); Bean, T. H., Bull. U. S. Fish Comm. (1887), *7*, 1888: 149 (common around Great Egg Harbor, New Jersey; eaten by weakfish); Henshall, Bull. U. S. Fish Comm. (1889), *9*, 1891: 373 (Cape Sable Cr., Cape Romano, and Big Gasparilla, Florida); Bean, B. A., Proc. U. S. nat. Mus., *14*, 1892: 93 (abund., Cape Charles City, Virginia); Evermann and Kendall, Bull. U. S. Fish Comm. (1892), *12*, 1894: 105 (Galveston, Texas); Moore, Bull. U. S. Fish Comm. (1892), *12*; 1894: 359 (abund., size, Sea Isle City, New Jersey); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 443 (descr., range, synon.); Smith, Bull. U. S. Fish Comm. (1897), *17*, 1898: 92 (abund., season, Woods Hole, Massachusetts); Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 56 (Florida locals.); Gilbert, Proc. Wash. Acad. Sci., *2*, 1900: 163 (Mamanguape, Brazil); Linton, Bull. U. S. Fish Comm. (1899), *19*, 1901: 440 (food, parasites); Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 310 (synon., forage fish); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20*, 1902: 88 (descr., range, Puerto Rico; synon.); Schreiner and Miranda-Ribeiro, Arch. Mus. nac., Rio de J., *12*, 1903: 93 (Rio de Janeiro); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 214 (descr., synon., New York); Linton, Bull. U. S. Bur. Fish. (1904), *24*, 1905: 353 (food, parasites); Barbour and Cole, Bull. Mus. comp. Zool. Harv., *50*, 1906: 156 (Progreso, México); Breder, Zoologica, N. Y., *2* (15), 1922: 338 (Sandy Hook, New Jersey); Metzelaar, Bijdr. Dierk. Amst., 1922: 134 (Curaçao).

Anchovia brownii Fowler, Rep. N. J. St. Mus. (1905), 1906: 109 (descr., New Jersey); Fowler, Rep. N. J. St. Mus. (1906), 1907: 267, pl. 85 (ill.); Smith, N. C. geol. econ. Surv., *2*, 1907: 133 (descr., range, abund., forage fish); Jordan and Dickerson, Proc. U. S. nat. Mus., *34*, 1908: 12 (Tampico, México); Weymouth, Proc. U. S. nat. Mus., *38*, 1910: 136 (Cameron, Louisiana); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 216 (New Jersey, North Carolina, Florida Keys, San Domingo, Puerto Rico, Rio de Janeiro); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31*, 1913: 742 (habitat, spawn. time, food, parasites, Woods Hole, Massachusetts); Fowler, Copeia, 1915: 50 (San Domingo); Latham, Copeia, 1919: 55 (Orient, Long Island, New York); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 204, pl. 14, fig. 1 (synon., descr., range, Colón and Porto Bello, Panama); Breder, Zoologica, N. Y., *4* (4), 1925: 152 (large schools, Caledonia Bay, Panama); Nichols and Breder, Zoologica, N. Y., *9* (1), 1927: 43 (descr., range, abund. New York to Woods Hole, Massachusetts; size); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 205, fig. 38 (diagn., range, abund., Puerto Rico).

Anchoviella epsetus Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67* (11), 1926: 396 (synon., descr., range; Rio de Janeiro, "Sambaia" [probably Sambara], Brazil, and Montevideo, Uruguay, specimens are *tricolor*; specimens from Key West and Tortugas, Florida, are *lamprotaenia*); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43* (1), 1928: 110 (descr., food, spawn. season, size, range, Chesapeake Bay); Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 46 (descr., range, Port-au-Prince, Haiti); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 71, text fig. (range, spawn., food, abund.); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 43 (descr., range); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 48 (synon., range); Hildebrand and Cable, Bull. U. S. Bur. Fish., *46*, 1930: 388 (econ. import., spawn., develop. of eggs and young, growth rate, food); Kendall, Bull. Boston Soc. nat. Hist., *58*, 1931: 11 (Portland, Maine); Vladykov, Proc. N. S. Inst. Sci., *19* (1), 1935: 3, 55, fig. 31

(Halifax Harbor, Nova Scotia); Hubbs, Publ. Carneg. Instn. Wash., 457, 1936: 175 (discus. ident., Rio Champoton and Campeche, Yucatán); Bigelow and Schroeder, Bull. U. S. Bur. Fish., *48* (20), 1936: 328 (Portland, Maine; Halifax Harbor, Nova Scotia); Howell-Rivero, Handbk. Jamaica, 1936: 1, in reprint (Port Antonio, Jamaica); Gunter, Ecol. Monogr., *8*, 1938: 337 (spawn., abund., Louisiana); Gunter, Amer. Nat., *72*, 1938: 78, 79; Gunter, Ecology, *22* (2), 1941: 203–208 (killed by freeze, Texas); Fowler (in part, not of Linnaeus), Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (Brazilian recs., in part *tricolor*).

Anchoa hepsetus hepsetus Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 57, fig. 21 (synon., descr., range).

Anchoa hepsetus colonensis Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 60, fig. 22 (orig. descr.; type local. Colón, Panama; type USNM 117664; cf. typical *hepsetus*; range).

Anchoa hepsetus Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 32 (shallow water, temp., salinity, length frequencies by months, sex. develop. in spring, Texas).

Doubtful References:

Anchovia brownii Jordan and Thompson, Bull. U. S. Bur. Fish. (1904), *24*, 1905: 233 (Garden Key, Florida; some, if not all, were *lamprotaenia*); Fowler, Proc. Acad. nat. Sci. Philad., *58*, 1906: 84 (Florida Keys; in part, if not all, *lamprotaenia*).

Engraulis brownii Lampe, Fisch. Dtsch. Südpolar Exped., 1901–1903, III, Die Hochsee und Küsten Fische, *15*, Zool. 7, 1914: 216 (Cape Verde, So. Africa; ident. needs verification).

Engraulis hepsetus Fowler, Bull. Amer. Mus. nat. Hist., *70* (1), 1936: 183 (descr. based on New Jersey specimens; rec. for Cape Verde after Lampe).

Negative References:

Stolephorus brownii Jordan, Proc. U. S. nat. Mus., 7, 1885: 106 (abund. Key West, Florida; USNM 35000 listed; these exam. and found to be *lamprotaenia*); Puyo, Bull. Soc. Hist. nat. Toulouse, *80*, 1945: 100, fig. 1 (descr., French Guiana; descr. and ill. appear to be unnamed new species of *Anchoviella*); Puyo, Faune Emp. Franc., 12, Poiss. Guiane Franç., 1949: 154 (see Puyo, 1945).

Anchovia brownii Starks, Stanf. Univ. Publ., Univ. ser., 1913: 10 (Natal, Brazil; specimens are *tricolor*).

Anchoa lyolepis (Evermann and Marsh) 1902

Dusky Anchovy, Manjúa (Cuba)

Figure 42

Study Material. At least 22 specimens, 45–70 mm TL; juveniles, including the type material, also at hand for comparison; from off St. Vincent Island, Florida; Mobile Bay, Alabama; Mississippi Sound, Mississippi; Grand Isle, Louisiana; Galveston and Aransas Pass, Texas; several places in Puerto Rico, Cuba, and St. Martin, West Indies.

Distinctive Characters. This species is quite distinctive. It is probably nearest to *lamprotaenia*, from which it differs rather prominently in the lower head, the longer snout, longer and narrower cheek, and in the more posteriorly placed anal fin.

Description. Proportional dimensions in per cent of standard length, and counts, based on *Study Material*, 45–70 mm TL.

Body: depth 16.6–20.
Head: length 27–32.2.
Snout: length 5.9–6.6.
Eye: diameter 5.5–7.0.
Postorbital: distance 15.4–16.7.
Maxillary: length 21–27.

Mandible: length 20–22.2.
Anal fin: length of base 19–22.5.
Pectoral fin: length 14–15.4.

Scales: *ca.* 40–44.

Gill rakers: 15–21+19–26 (most frequently 18 or 19+20–22).
Fin rays: dorsal 12–15; anal 19–23; pectoral 12–14.
Vertebrae: 41–43 (9 specimens).

Body very slender, rather strongly compressed, its depth 5.0–6.0 in SL. Head 3.1–3.7 in SL, its depth about equal to its postorbital length. Snout extending nearly its full length beyond tip of mandible, 4.3–5.5 in head. Eye scarcely longer than snout in large specimens, 4.25–5.0 in head. Postorbital part of head slightly longer than snout and eye, 1.7–2.0 in head. Maxillary rather bluntly pointed, its upper margin gently rounded, not quite reaching margin of opercle, 1.15–1.3 in head. Mandible 1.25–1.55. Cheek narrow, about as long as snout and eye, its posterior angle acute, about 25°.

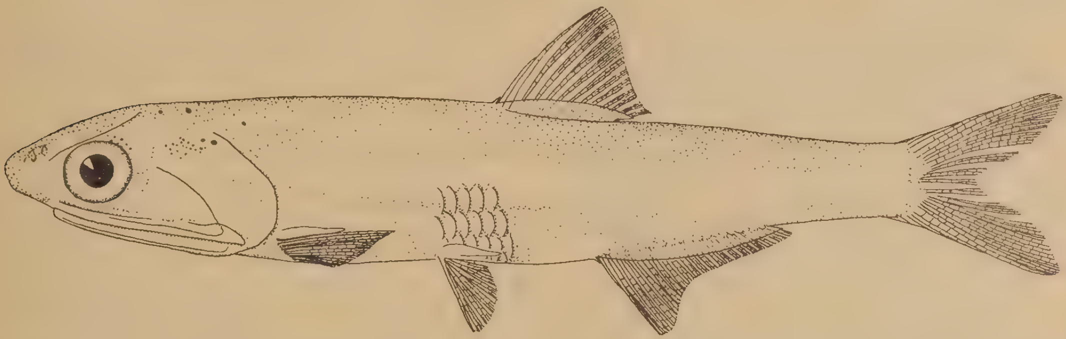

Figure 42. *Anchoa lyolepis*, 63 mm TL, from Hucares, Puerto Rico, USNM 125580. Drawn by Louella E. Cable.

Dorsal fin moderately high anteriorly, its longest rays reaching nearly to tip of last ray if deflexed, its origin usually a little nearer to base of caudal than to tip of snout. Anal with origin under or slightly behind base of last dorsal ray, its base 4.45–5.3 in SL. Pelvic inserted equidistant between origin of anal and pectoral base, sometimes a little nearer to the latter. Pectoral rather falcate, failing to reach pelvic by 50–75% of diameter of eye, the last ray only about half as long as the first or uppermost ray, 1.75–2.1 in head. Axillary scale of pectoral rather short and broad, about 50–75% of length of pectoral, 2.9–3.5 in head.

Color. In alcohol pale. Side of head silvery. Lateral band bright silvery, fully as wide as eye (often dusky in specimens preserved in formalin); back and both dorsal and caudal fins with dusky dots, these frequently present at base of anal also.

Size. The 70-mm (2.8 in.) specimen measured is the largest one seen, and it is probably near the maximum size attained.

Reproduction. Specimens of two different lots taken during February in Puerto Rico contain well-developed roe.

Variation. Specimens from the Gulf of Mexico have more numerous gill rakers than those from farther south, but they seem to agree in other respects.

Commercial Importance. So far as known, this Anchovy is not used directly as food by man. However, where it is common, as in Puerto Rico, it no doubt furnishes considerable forage for larger predatory fishes that are used as food by man.

Range and Habitat. The range extends from the Gulf coast of the United States through the West Indies to the Gulf of Venezuela. Although some of the specimens examined were taken with trawls hauled at depths down to 30 fms., most of them were seined along the shore.

Synonyms and References:

Stolephorus lyolepis Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 89, fig. 13 (orig. descr. based on juveniles, 30–37 mm long; type local. Culebra, Puerto Rico; type USNM 49528).

Stolephorus choerostoma Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 88 (descr., synon., specimens in part re-exam., not *E. choerostoma* Goode).

Anchovia platyargyrea Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 216, fig. 4 (orig. descr.; type local. St. Martin, West Indies; type ANSP 1416; cf. *E. choerostoma* Goode; type material, exam. by me, is *S. lyolepis* E. and M.).

Anchoviella choerostoma Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 404 (specimens from e. coast of Panama and Puerto Rico probably this species); Beebe and Tee-Van, Zoologica, N. Y., 10 (1), 1928: 47, fig. (refs., descr., distr., abund. Port-au-Price, Haiti; descr. and fig. show it to be *S. lyolepis* E. and M., not *E. choerostoma* Goode).

Anchoviella lyolepis Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 47, fig. (refs., descr., Port-au-Prince, Haiti; descr. based on juveniles); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (synon., Puerto Rico only).

Engraulis platyargyreus Fowler, Proc. Acad. nat. Sci. Philad., *80*, 1928: 468 (St. Lucia, B.W.I.).

Anchovia choerostoma Nichols, N. Y. Acad. Sci., *10* (2), 1929: 205, fig. 39 (refs., diagn., Puerto Rico; *S. lyolepis* E. and M., not *E. choerostoma* Goode).

Anchoviella platyargyrea Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (ref. to orig. descr.); Beebe and Hollister, Zoologica, N. Y., *19* (6), 1935: 211 (Union I., Grenadines, West Indies).

Anchoa lyolepis Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 65, fig. 25 (synon., descr., relation., range); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 43 (synon.).

Doubtful Reference:

Engraulis (*Stolephorus*) *argentivittatus* Regan, Ann. Mag. nat. Hist., (7) *13*, 1904: 257 (orig. descr.; type local. Pas Penas, Jalisco, México; type in BMNH).

Anchoa filifera (Fowler) 1915

Figure 43

Study Material. At least 11 specimens, ranging between 55–75 mm TL. In addition to the three types from Port-of-Spain, Trinidad, 16 additional specimens from Kingston, Jamaica, were examined.

Distinctive Characters. This species in general resembles *A. lyolepis*, from which it differs: in the produced ray of the pectoral, the fin itself being longer; the more anterior position of the dorsal and anal fins; and the slightly fewer vertebrae. It differs from

A. howelli Hildebrand (3: 105), known only from Santos and Rio de Janeiro, Brazil, in having fewer anal rays, gill rakers, and vertebrae, longer pectoral and pelvic fins, and a slightly more posteriorly inserted pelvic fin. For details, compare the descriptions of the two species.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 55–75 mm TL.

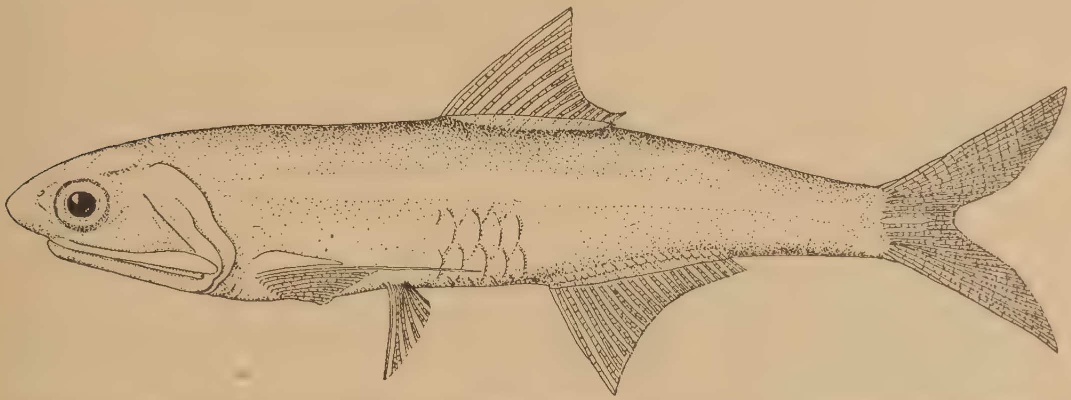

Figure 43. *Anchoa filifera*, 70 mm TL, from Kingston, Jamaica, USNM 127611. Drawn by Alice C. Mullen.

Body: depth 17.8–20.
Head: length 28–29.3.
Snout: length 5.17–5.85.
Eye: diameter 5.9–7.0.
Postorbital: distance 14.7–16.
Maxillary: length 20.5–23.
Mandible: length 18–21.
Anal fin: length of base 18.5–21.

Pectoral fin: length (without filament) 15.5–16.6.

Scales: *ca.* 39 or 40.
Gill rakers: 17–19 + 20–23.
Fin rays: dorsal 13–15; anal 19–23; pectoral 13 or 14.
Vertebrae: 39 or 40 (3 specimens).

Body strongly compressed, its depth 5.0–5.6 in SL. Head 3.4–3.6, its depth slightly exceeding the postorbital length. Snout long, projecting nearly its full length beyond mandible, only a little shorter than eye, 5.0–5.5 in head. Eye small, 4.2–4.8. Postorbital part of head 1.6–1.8 in head. Maxillary not sharply pointed, its upper margin rounded, reaching nearly to margin of opercle, 1.25–1.3 in head. Mandible 1.4–1.5. Cheek narrow, equal to eye and snout, its posterior angle sharp, about 30°.

Dorsal fin rather high anteriorly, its longest rays reaching nearly to tip of last ray if deflexed, its origin slightly nearer to tip of snout than to base of caudal. Anal with origin nearly under the beginning of the last third of dorsal base, the base 4.8–5.4 in SL. Pelvic reaching much more than halfway to anal, inserted a little nearer to pectoral base than to anal origin. Pectoral with upper ray produced, its filament (often broken) extending to, and possibly beyond, tip of pelvic in perfect specimens, the fin, without filament (second ray), reaching base of pelvic, 1.6–1.8 in head.

AXILLARY SCALE of pectoral about 66% of length of fin (without filament), 2.8–3.5 in head.

Color. In alcohol pale. Side of head and lower part of side silvery. Silvery lateral band as wide as eye (often dusky in specimens preserved in formalin). Upper parts of head and back with numerous punctulations not arranged in longitudinal series.

Size. The longest specimen seen (type) is 75 mm (3 in., 61 mm SL).

Range. This species, as here understood, is known from Puerto Rico, Jamaica, Haiti, and Trinidad.

Synonyms and References:

Anchovia filifera Fowler, Proc. Acad. nat. Sci. Philad., 1915: 524, fig. 2 (orig. descr.; type local. Port-of-Spain, Trinidad; type ANSP 45080; cf. *A. platyargyrea* = *A. lyolepis* and *A. choerostoma*. Gill rakers given as 25 + 22, total anal rays 25, depth 4.75. My counts and measurements give gill rakers 18 + 22, anal rays 23, depth 5.0. Orig. fig. shows mandible projecting too far in advance of vertical from anterior margin of eye; anal fin rather too far back, its origin actually well in advance of vertical from base of last dorsal ray).

Anchoviella filifera Fowler, Proc. biol. Soc. Wash., *43*, 1930: 146 (Jamaica); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish (1928), 2, 1930: 50 (ref.).

Anchoviella longipinna Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 48, fig. (orig. descr.; type local. Bizoton, Haiti; type NYZS 7460; also Port-au-Prince, Haiti; type material not seen; descr. and fig. agree well with *A. filifera* from Jamaica and Trinidad).

Anchoa filifera Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 105, fig. 45 (synon., descr., range).

Genus *Anchoviella* Fowler 1911

Anchoviella Fowler, Proc. Acad. nat. Sci. Philad., *43*, 1911: 211; genotype by original designation, *Engraulis perfasciatus* Poey 1861.

Amplova Jordan and Seale, Copeia, 1925: 31; type species *Anchovia brevirostris* Meek and Hildebrand 1923 equals *Amplova balboae* Jordan and Seale 1925.

Characters. BODY usually slender, its depth less than 25% of SL (except in *pallida*, 26–28.5%). GILL RAKERS usually fewer than 35 on lower limb (except in *pallida*, which may have as many as 45), not known to increase in number with age. ANAL fin rather short, with fewer than 30 rays, its origin usually under or posterior to middle of dorsal base (somewhat in advance of middle of dorsal in *blackburni* and *jamesi*). VERTEBRAE 39–45.

Size. Although a maximum length of 155 mm has been reported for *eurystole*, the largest in the collections studied is only 130 mm TL, and the other species are smaller.

Remarks. *Anchoviella* obviously is closely related to *Anchoa*, from which it differs in the shorter and distally square-to-round maxillary. This structure, variable in length in both genera, may reach only a little beyond the vertical from the posterior margin of the eye, as in *Anchoviella jamesi*, or it may reach to the joint of the mandible, as in *Anchoviella eurystole*. Indeed, Jordan and Seale (6: 31) erected a new genus, *Amplova*, on the basis of the very short maxillary in *A. balboae*, a species common on the Pacific

Table V. Frequency Distribution of Anal Rays in *Anchoviella*.*

Species	Number of Anal Rays												
	15	16	17	18	19	20	21	22	23	24	25	26	27
eurystole	6	8	17	7	1	—	—	—	—	—	—	—	—
estauquae	1	1	2	—	—	—	—	—	—	—	—	—	—
perfasciata	6	9	22	9	2	—	—	—	—	—	—	—	—
brevirostris	—	2	1	1	1	—	—	—	—	—	—	—	—
guianensis	—	—	—	1	1	—	—	—	—	—	—	—	—
alleni	—	—	—	4	4	—	—	—	—	—	—	—	—
pallida	—	—	—	—	—	—	—	—	—	1	1	1	—
elongata	—	—	—	—	—	—	—	4	5	5	—	—	—
lepidentostole	—	—	—	—	—	—	—	—	1	—	1	—	—
blackburni	—	—	—	—	—	—	—	—	—	—	2	2	3
jamesi	—	—	—	—	1	—	1	—	—	—	—	—	—

* Anal rays given as 9–11 for *cayennensis*, see p. 212.

Table VI. Frequency Distribution of Gill Rakers on Upper Limb in *Anchoviella*.*

Species	Number of Gill Rakers on Upper Limb of First Arch																								
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
eurystole	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4	11	12	7	4	—	—	—	—	—	—
estauquae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	—	—	—	—	—
perfasciata	—	—	—	—	—	—	—	—	1	12	20	16	5	3	—	—	—	—	—	—	—	—	—	—	—
brevirostris	—	—	—	4	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
guianensis	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
alleni	—	—	—	—	—	—	1	7	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
pallida	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	2	1
elongata	—	—		—	—	—	—	7	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
lepidentostole	—	—	—	—	—	—	—	3	1	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—
blackburni	1	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
jamesi	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* When the number of counts exceeds the number of specimens listed in the text, the gill rakers on both anterior arches in at least some of the specimens were counted.

Table VII. Frequency Distribution of Gill Rakers on Lower Limb in *Anchoviella*.*

pecies	Number of Gill Rakers on Lower Limb of First Arch																														
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
rystole	—	—	—	—	—	—	—	—	—	—	—	—	2	10	13	10	3	5	2	—	—	—	—	—	—	—	—	—	—	—	—
tauquae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—
rfasciata	—	—	—	—	—	—	—	—	—	—	6	19	17	9	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
revirostris	—	—	—	2	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
uianensis	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
lleni	—	—	—	—	—	—	—	—	1	5	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
llida	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	1	—	1	—	—	1
ongata	—	—	—	—	—	—	—	2	10	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
pidentostole	—	—	—	—	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
lackburni	1	4	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
mesi	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

When the number of enumerations exceeds the number of specimens listed in the text, the gill rakers have been counted on both nterior arches in at least some of the fish.

coast of Panama. However, there are species quite intermediate between the type species of *Amplova* (*balboae*) and that of *Anchoviella* (*perfasciata*). For that reason *Amplova* was reduced to subgeneric rank (*3*: 108).

The very short maxillary in some species of *Anchoviella* furnishes a near transition from the Engraulidae to the Clupeidae; but other family characters, such as the projecting snout and the anteriorly more-or-less embedded and widely separated premaxillaries, remain as in other Engraulidae.

Range and Habitat. The genus seems to be restricted to the two coasts of America, ranging in the Atlantic from Woods Hole, Massachusetts, at least to southern Brazil, and in the Pacific from southern California to northern Peru. Most of the species enter fresh water. In fact, several of the South American species from the Atlantic drainage are known only from freshwater lakes and streams, a few of them having been taken a great distance from the sea.

Key to Species of the Western Atlantic

1a. Maxillary usually extending beyond posterior rim of orbit by a distance equal to or greater than diameter of pupil. Subgenus *Anchoviella*.
  2a. Origin of anal posterior to middle of dorsal base, sometimes entirely behind dorsal; not more than 20 anal rays.
    3a. Origin of anal clearly posterior to dorsal base, generally under or behind tips of dorsal rays if deflexed; gill rakers 24–28 + 27–33.
      4a. Longest rays of dorsal failing to reach tip of last ray if deflexed; eye 3.75–4.5 in head, 2.1–2.5 in postorbital; maxillary 15.8–17.8% of SL; postorbital 13.8–15.5% of SL.
      eurystole (Swain and Meek) 1884, p. 208.
      4b. Longest rays of dorsal reaching beyond tip of last ray if deflexed; eye 4.4–4.8 in head, 2.5–2.75 in postorbital; maxillary 17.5–18.7% of SL; postorbital 15.5–15.8% of SL.
      estauquae Hildebrand 1943, p. 211.
    3b. Origin of anal under or slightly behind base of last 2 or 3 rays of dorsal; gill rakers usually 13–23 + 19–28.
      5a. Only 9–11 anal rays; depth of body less than 14% of SL.
      cayennensis (Puyo) 1945, p. 212.
      5b. 15 anal rays or more; depth of body more than 15% of SL.
        6a. Pectoral with 14–16 rays; gill rakers 19–23 + 24–28.
        perfasciata (Poey) 1860, p. 213.
        6b. Pectoral with 11–13 rays; gill rakers 18 or fewer on upper limb, generally fewer than 25 on lower limb.
          7a. Gill rakers 13 or 14 + 18 or 19; pectoral failing to reach base of pelvic by diameter of eye, 11.2–13.8% of SL, 1.7–2.0 in head. *brevirostris* (Günther) 1868, p. 216.

7b. Gill rakers 16–18 + 22–26; pectoral failing to reach pelvic by a distance considerably less than eye, 14.7–16.8% of SL, 1.4–1.6 in head.

8a. Eye 7.0–7.5% of SL, 3.2–3.5 in head; cheek fully as long as eye, with a definite posterior angle of about 60°; axillary scale of pectoral about 50% of fin, 2.4 in head; a median dark line posterior to anal fin.
guianensis (Eigenmann) 1912, p. 217.

8b. Eye 5.5–6.25% of SL, 3.7–4.1 in head; cheek scarcely as long as eye, without a definite posterior angle; axillary scale of pectoral about 75% of length of fin, 2.0–2.2 in head; no median dark line posterior to anal fin.
alleni (Myers) 1940, p. 219.

2b. Origin of anal under, or in advance of, middle of dorsal base; 22–29 anal rays.

9a. Anal with 28 or 29 rays; pectoral extending to midlength of pelvic.
nattereri (Steindachner) 1879, p. 220.

9b. Anal with fewer than 28 rays; pectoral usually failing to reach base of pelvic.

10a. Gill rakers 28–34 + 36–45; depth about 26–28.5% of SL; pectoral extending slightly beyond base of pelvic, 19–20% of SL.
pallida (Starks) 1913, p. 221.

10b. Gill rakers 18 or fewer on upper limb, 24 or fewer on lower limb; depth 25% of SL or less; pectoral failing to reach base of pelvic, 16.7% of SL.

11a. Maxillary extending beyond orbit a distance about equal to diameter of eye, 15–20% of SL; mandible 15.8–18.8; gill rakers 17 or 18 + 19–24; origin of anal under or slightly behind middle of dorsal base.

12a. Depth of body 17.5–20% of SL; head 25.5–28%; postorbital part of head 12–13.3%; mandible 17.8–18.8%; silvery lateral band poorly defined, narrower than eye. *elongata* (Meek and Hildebrand) 1923, p. 223.

12b. Depth of body 22–25% of SL; head 22.7–23.7%; postorbital 10.7–11%; mandible 15.8–16.3%; silvery lateral band well defined, broader than eye.
lepidentostole (Fowler) 1911, p. 224.

11b. Maxillary extending beyond orbit a distance equal to only half of diameter of eye, 12–15% of SL; mandible 12.3–14.8; gill rakers 10–12 + 15–17; origin of anal well in advance of middle of dorsal base. *blackburni* Hildebrand 1943, p. 226.

1b. Maxillary extending a little less than diameter of pupil beyond orbit.
Subgenus *Amplova*.
jamesi (Jordan and Seale) 1926, p. 227.

Anchoviella eurystole (Swain and Meek) 1884

Silver Anchovy

Figure 44

Study Material. At least 29 specimens, 55–130 mm, from: Woods Hole and Menemsha Bight, Massachusetts; Noank, Connecticut; Long Island, New York; Brigantine Bay, New Jersey; and Beaufort, North Carolina.

Distinctive Characters. A. estauquae is the nearest relative of this species. The relationship is shown in the account of that species (p. 211).

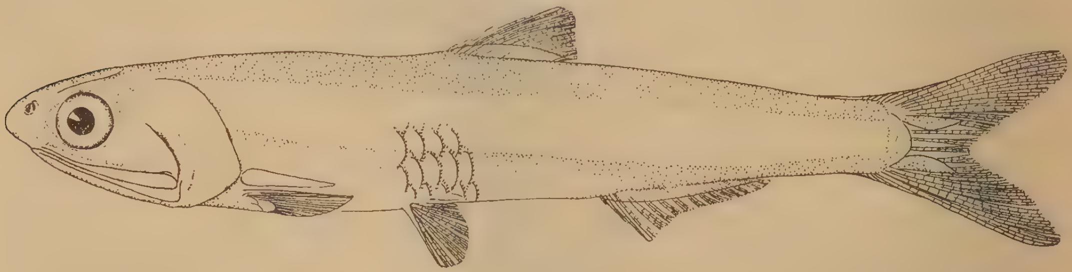

FIGURE 44. *Anchoviella eurystole*, 75 mm TL, from Woods Hole, Massachusetts, USNM 77778. Drawn by Louella E. Cable.

Description. Proportional dimensions in per cent of standard length, and counts, based on *Study Material*, specimens 55–130 mm.

Body: depth 15.4–19.
Head: length 25–28.5.
Snout: length 3.85–5.0.
Eye: diameter 5.7–7.0.
Postorbital: distance 13.8–15.5.
Maxillary: length 15.8–17.8.
Mandible: length 15–18.5.
Anal fin: length of base 12.5–16.

Pectoral fin: length 12.5–13.7.

Scales: *ca.* 40–45.
Gill rakers: 24–28+27–33 (most frequently 25 or 26+28–30).
Fin rays: dorsal 13–16; anal 15–18 (rarely 19); pectoral 15 or 16.
Vertebrae: 43–45 (3 specimens).

BODY slender, not strongly compressed, its depth 5.25–6.5 in SL. HEAD 3.5–4.0, its depth equal to length of postorbital part of head. SNOUT projecting about half of its length beyond mandible, only a little shorter than eye in large examples, 4.75–6.5 in head. EYE 3.75–4.5 in head, 2.1–2.5 in postorbital length of head. POSTORBITAL part of head 1.6–1.8 in head. MAXILLARY rather narrow, rounded distally, extending beyond orbit by a distance equal to about 1.3 diameter of eye, failing to reach joint of mandible by about half of diameter of pupil, 1.5–1.7 in head. MANDIBLE 1.45–1.75. CHEEK only a little shorter than snout and eye, its posterior angle about 45°. GILL RAKERS about 75% of length of eye, not broad or close-set, with moderate serrations on inner edge.

DORSAL fin low anteriorly, the longest rays failing to reach tip of last ray if deflexed, its origin usually somewhat nearer to tip of snout than to base of caudal. ANAL small, its origin wholly behind dorsal base, most frequently about under tips of longest deflexed rays, its base 6.25–8.0 in SL. PELVIC inserted nearly an eye's diameter in advance of dorsal and usually somewhat nearer to pectoral base than to anal origin, reaching much less than halfway to anal. PECTORAL usually failing to reach pelvic by more than diameter of eye, 1.8–2.2 in head. AXILLARY SCALE of pectoral long and narrow, generally failing to reach tip of fin by about half of diameter of pupil, 2.25–3.0 in head.

Color. In alcohol, some rather pale above, others bluish. Side of head and lower part of side on some silvery. Silvery lateral band about as broad as eye in small specimens, broader and less distinctly outlined ventrally in large ones.

Size. Although a maximum total length of 155 mm (6.2 in.) has been reported, the largest example in the collections examined in this study is only 130 mm TL.

Development. The information on the development of the eggs and larvae that follows is based mostly on the work of Kuntz and Radcliffe (*10*: 116), who took the eggs in tows during August 1915 off Gay Head, Massachusetts.

The egg is buoyant, highly transparent, and ellipsoidal, having a long axis of 1.15–1.25 mm, a short axis of 0.55–0.8 mm. The yolk, as usual among anchovies, has a network of lines on its surface, giving the appearance of large cells. In this anchovy, as in other species studied, the blastodisc forms at one end of the elongated egg. The egg is similar to that of *Anchoa hepsetus* but seems to be slightly shorter though scarcely narrower. The development, so far as known, is identical in the two species.

The newly hatched fish is about 3.0 mm long, being slightly shorter than the newly hatched larva of *A. hepsetus*, in keeping with the rather smaller egg. The body is very slender, and the vent as usual in the larvae of anchovies is situated very far back, in this species about at the beginning of the distal fourth of the body. Black chromatophores occur in a series along the intestine posterior to the yolksac and at the base of the ventral finfold behind the vent. A day or so after hatching, the yolk is virtually all absorbed and the fish has grown to a length of about 4.0 mm. The young fish, when 5.2 mm long, has developed a large oblique, terminal mouth, the fins are becoming differentiated, and the convoluted intestine, incompletely invaginated, is conspicuous. The chromatophores have become less conspicuous than in the earlier stages. The development in older stages apparently remains unknown.

Spawning. Although the duration of spawning has not been determined, it is at its height during July and August (*15*: 44).

Range and Habitat. This anchovy ranges from Woods Hole, Massachusetts, at least as far south as Beaufort, North Carolina. The southern limit of its range remains undetermined, for no specimens of the genus are at hand or seem to be reported for the coast between Beaufort, North Carolina, and Melbourne Beach, Florida; those from the last mentioned locality are *A. perfasciata*. During some summers this anchovy is common at Woods Hole; during other summers it seems to be missing. Off Connecticut, New York, and New Jersey it appears only occasionally. It is not recorded for

Chesapeake Bay; and for North Carolina it is known by only one specimen taken during the summer of 1913 in inside waters at Beaufort, where intensive collecting was carried on during many years. It has been stated often that the home of the Silver Anchovy is in the Gulf Stream. The basis for this statement is unknown and certainly stands in need of verification, especially as it has been rather definitely established that the specimens known from North Carolina northward represent a species distinct from the examples from the West Indies northward to Melbourne Beach, Florida. All records of *argyrophana* based on northern specimens apparently apply to *eurystole* as herein understood.

Synonyms and References:

Stolephorus perfasciatus Swain (not of Poey), Bull. U. S. Fish Comm. (1882), *2*, 1883: 55 (descr. of one from Woods Hole, Massachusetts; indicated as orig. descr. of *S. eurystole* by Swain and Meek); Jordan and Gilbert (not of Poey), Bull. U. S. nat. Mus., 16, 1883: 273 (descr. of one from Woods Hole, Mass., apparently the same one used by Swain; West Indies includ. in the range where *eurystole* does not occur); Bean, T. H. (not of Poey), Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 217 (descr., Noank, Connecticut, and Gravesend Bay, Long Island, New York; in part exam. by me and found to be *A. eurystole*).

Stolephorus eurystole Swain and Meek, Proc. Acad. nat. Sci. Philad., 1885: 35 (descr. by Swain and by Jordan and Gilbert above referred to as orig.; type local. Woods Hole, Mass.; type destroyed by fire. This species was said to differ from *Engraulis perfasciatus* Poey chiefly in the greater number of anal rays, a broader lateral band, and a larger size; this northern species apparently reaches a somewhat larger size, but at most there is only a small average difference in the number of anal rays, and the width of the lateral band varies with age. For diagn. char., see Key); Bean, T. H., Bull. U. S. Fish Comm. (1887), *7*, 1888: 150, pl. 3, fig. 19 (Ocean City and Longport, New Jersey).

Stolephorus argyrophanus Jordan and Evermann (not of Cuvier and Valenciennes), Bull. U. S. nat. Mus., 47 (1), 1896: 444 (descr. apparently based on type of *E. eurystole*; range "Gulf Stream, occasionally northward"); Smith (not of C. and V.), Bull. U. S. Fish Comm. (1897), *17*, 1898: 92 (occur. assoc. with other species round Woods Hole, Massachusetts); Bean, T. H. (not of C. and V.), Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 216 (descr., Ocean City, New Jersey, and Fire Island, New York).

Anchovia eurystole Fowler, Rep. N. J. St. Mus. (1905), 2, 1906; 109 (descr., Ocean City and Longport, New Jersey; ident. of this species and *Engraulis argyrophanus* C. and V. questioned); Fowler, Rep. N. J. St. Mus. (1906), 1907: 267, fig. (name); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 219 (Corson Inlet, New Jersey); Fowler, Proc. Acad. nat. Sci. Philad., *64*, 1912: 34 (Long Beach, New York).

Anchovia argyrophana Sumner, Osburn, and Cole (not of C. and V.), Bull. U. S. Bur. Fish (1911), *31* (2), 1913: 743 (abund., where and how taken, Woods Hole, Massachusetts; parasites); Kuntz and Radcliffe (not of C. and V.), Bull. U. S. Bur. Fish., *35*, 1917: 116 (embryol., larval develop.); Nichols and Breder (not of C. and V.), Zoologica, N. Y., 9 (1), 1927: 43, fig. (diagn., distr., life hist., size); Hildebrand (not of C. and V.), Copeia, 1941: 224 (Beaufort, North Carolina).

Anchoviella argyrophana Jordan and Seale (not of C. and V.), Bull. Mus. comp. Zool. Harv., *67*, 1926: 402 (descr. of one from Provincetown, Mass.; *argyrophana* and *eurystole* regarded ident. by Jordan from exam. of type of former in Paris, which had 19 anal rays instead of 17, as stated in orig. descr. But number of anal rays does not distinguish this species from *perfasciata*); Breder (not of C. and V.), Field Bk. Mar. Fish. Atl. Cst., 1929: 70, 71 (defined in key; range; "Gulf Stream species"; eggs, size); Jordan (not of C. and V.), Manual Vert. Anim. NE U. S., ed. 13, 1929: 43 (descr., range); Jordan, Evermann, and Clark (not of C. and V.), Rep. U. S. Comm. Fish. (1928), 2, 1930: 48 (range; *eurystole* in synon.).

Anchoviella eurystole Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 112, fig. 47 (descr., cf. *perfasciata*, range).

Doubtful References:

Anchovia perfasciata Nichols and Breder (probably not of Poey), Zoologica, N. Y., 9 (1), 1927: 42, fig. (diagn., N. Y. City area; distingu. char. of this species and one rec. as *argyrophana* not stated correctly; fig.

looks like *perfasciata*; as it is the same one used by Nichols [1929: 204], it may have been based on a West Indian specimen).

Anchoviella perfasciata Greeley, 28th Rep. N. Y. Conserv. Dept., Suppl., 15 (2), 1939: 83 (rare at Long Island; prabably *A. eurystole*).

Anchoviella estauquae Hildebrand 1943

Figure 45

Study Material. Holotype and 3 paratypes, about 77–92 mm TL (caudal fins damaged), 65–77 mm SL, collected on a sandy beach in Estauques Bay, Gulf of Venezuela, by the U.S.S. NIAGARA, on February 20, 1925.

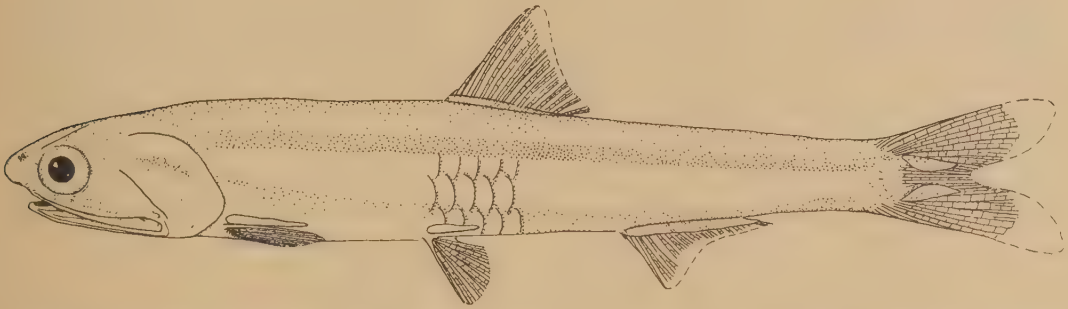

FIGURE 45. *Anchoviella estauque*, type specimen, 82 mm TL, 72 mm SL, from Gulf of Venezuela, USNM 119795. Drawn by Louella E. Cable.

Distinctive Characters. This species is very close to *A. eurystole*, from which it is difficult to separate it with the meager material at hand. The number of gill rakers is within the range of *eurystole*, but the rakers seem to be a little longer, certainly broader, apparently closer together, and the serrations on their inner edges are slightly smaller. The eye appears to be a little smaller and the postorbital part of the head is slightly longer. The dorsal fin is higher anteriorly and somewhat different in shape; the anal fin is placed farther back.

Description. Proportional dimensions in per cent of standard length, and counts, based on type material, 65–76 mm SL.

Body: depth 15.3–19.2.
Head: length 26–27.7.
Snout: length 5.0–5.55.
Eye: diameter 5.7–6.16.
Postorbital: distance 15.5–15.8.
Maxillary: length 17.5–18.7.
Mandible: length 17.3–18.5.

Anal fin: length of base 13.3–15.3.
Pectoral fin: length 12.8–14.3.

Scales: *ca.* 44–46.
Gill rakers: 26–28 + 30–32.
Fin rays: dorsal 13–15; anal 15–17; pectoral 15 or 16.
Vertebrae: 45 (1 specimen).

Body not strongly compressed, its depth 5.2–6.5 in SL. Head 3.6–3.7, its depth scarcely equal to its postorbital length. Snout projecting rather more than half of its length beyond mandible, only a little shorter than eye, 5.0–5.3 in head. Eye 4.4–4.8 in head, 2.5–2.75 in postorbital length of head. Postorbital part of head long, 1.73–1.77 in head. Maxillary rather narrow, rounded distally, extending beyond orbit a distance equal to about 1.3 diameter of eye, not quite to joint of mandible, 1.5–1.6 in head. Mandible 1.48–1.53. Cheek nearly as long as snout and eye, its posterior angle about 40°. Gill rakers scarcely as long as eye, broad and close-set, with minute serrations on inner edge.

Dorsal fin with longest rays reaching beyond tip of last ray if deflexed, its origin about equidistant between tip of snout and base of caudal. Anal with origin well behind tips of longest deflexed rays of dorsal, its base 6.5–7.5 in SL. Pelvic inserted about half of diameter of eye in advance of dorsal and nearly equidistant between base of pectoral and anal origin, reaching rather less than halfway to anal. Pectoral usually failing to reach pelvic by rather more than diameter of eye, 1.9–2.5 in head. Axillary scale of pectoral long, narrow, failing to reach tip of fin by a distance equal to or less than diameter of pupil, 2.3–2.7 in head.

Color. In alcohol, pale (originally in formalin). Sides of head bright silvery. Lateral band bright silvery, fully as broad as eye.

Range. This species is known only from the Gulf of Venezuela.

References:

Anchoviella estauquae Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 115, fig. 48 (orig. descr.; type local. Estauques Bay, Gulf of Venezuela; type USNM 119795; cf. *A. eurystole* and *A. perfasciata*); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 47 (ref., type and paratypes listed).

Anchoviella cayennensis (Puyo) 1945

Jamais-gouté

Study Material. None.

Distinctive Characters. The short maxillary, extending about a pupil's diameter posterior to a vertical at end of eye, the elongate body, with the depth more than 7 times in SL, and the very short anal, with 9–11 rays and with its origin below that of the last dorsal ray, show that this species is a very distinctive one, if Puyo's descriptions are reliable.

Description. Based on published accounts and figures by Puyo (see References below). Body very elongate, lightly compressed anteriorly and progressively more rounded posteriorly (in transverse section); depth a little more than 7 times in total body length (SL). Head a little more than 5 times in same; a sort of transverse keel present on superior surface of head. Snout somewhat rounded. Eye equal to snout (pupil shown as abnormally large in most of Puyo's drawings, probably in error). Maxillary rounded at the end, extending about a normal pupil's diameter posterior to vertical at posterior border of eye (in Puyo's published figure). LOWER JAW slightly shorter than the upper.

DORSAL fin origin midway between tip of snout and caudal base. ANAL fin origin under base of last dorsal ray. FIN RAYS: dorsal 12, anal 9–11. PECTORAL fin slightly less than twice the length of ventral, extending somewhat more than half of the distance from its origin to that of the pelvic.

Color (from Puyo). On the whole, body clear blackish (apparently in formalin); opercular bones iridescent. A black longitudinal band on each side; band towards posterior part of body giving off irregular transverse projections from its lower border; lateral band merging gradually into an irregular streak on middle caudal rays; dark band on body bordered below by a silvery band wider than eye diameter. Dorsal and anal pale. Pectoral and pelvic hyaline. Caudal lighter than the body, its border lightly tinted with brown.

Size. Puyo's two type specimens, the only examples so far recorded, were 130 and 135 mm SL.

Habits. Said to be confined to estuaries and river mouths.

Range. Known only from the coast of French Guiana. The types were taken in the Cayenne River, as far up as Macouria,[9] but fishermen told Puyo they found this species also in the Mahury River and at the mouth of the Kourou.

References:

Stolephorus cayennensis Puyo, Bull. Soc. Hist. nat. Toulouse, *80*, 1945: 101, fig. 1 (descr., Cayenne R., French Guiana); Puyo, Faune Emp. Franç., 12, Poiss. Guyane Franç., 1949: 157, fig. 80 (descr.).

Anchoviella perfasciata (Poey) 1860

Flat Anchovy, Manjúa (Cuba)

Figure 46

Study Material. At least 41 specimens, 60–105 mm TL, from Puerto Rico, Jamaica, Cuba, and St. Lucia; also some poorly preserved specimens from off Melbourne Beach, Key West, Tortugas, and Pensacola, Florida, and from Mississippi Sound, probably belonging to this species.

Distinctive Characters. This species differs from *A. eurystole* principally in having a larger eye, a higher dorsal fin, a more anteriorly placed anal fin, a longer pectoral fin, and fewer gill rakers.

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 41 specimens, 60–105 mm TL.

Body: depth 15.4–18.2.	*Snout*: length 4.0–5.25.
Head: length 23.3–25.6.	*Eye*: diameter 6.6–7.7.

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[9] Stieler's *Atlas* shows Macouria to be on the coast, as is Kourou.—Y. H. O.

Postorbital: distance 11.7–13.3.
Maxillary: length 15.2–17.3.
Mandible: length 15–17.2.
Anal fin: length of base 13.7–15.3.
Pectoral fin: length 12.2–14.2.
Scales: *ca.* 40–44.
Gill rakers: 19–23+24–28 (most frequently 19–21+26 or 27).
Fin rays: dorsal 12–15; anal 15–18; pectoral 14–16.
Vertebrae: 42–44 (7 specimens).

Body not strongly compressed, its depth 5.5–6.5 in SL. Head 3.9–4.3 in SL, its depth slightly exceeding its postorbital length. Snout much shorter than eye, extending about half of its length beyond mandible, 4.2–5.75 in head. Eye 3.25–4.0 in head, 1.6–2.0 in postorbital length of head. Postorbital 1.9–2.1 in head. Maxillary slightly expanded and rounded distally, generally extending about an eye's diameter beyond rim of orbit, failing to reach joint of mandible by nearly diameter of pupil, 1.4–1.55 in head. Mandible 1.4–1.66. Cheek slightly longer than eye, its posterior angle about 60°. Gill rakers shorter than eye, broad, not close-set, with short coarse serrations on inner edge.

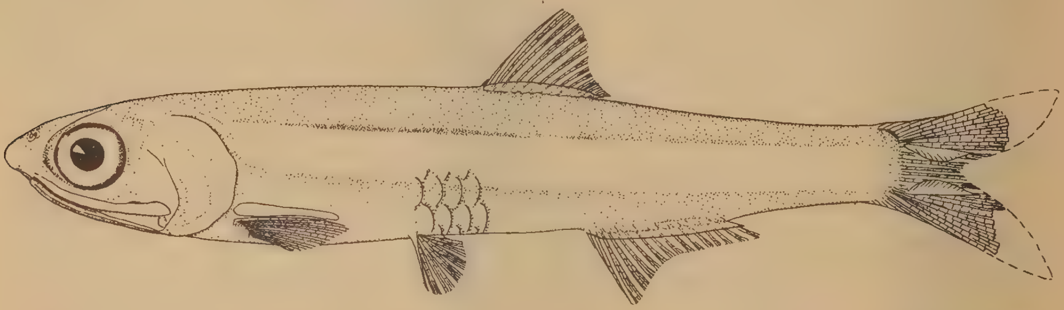

Figure 46. *Anchoviella perfasciata*, 100 mm TL, 83 mm SL, from Cuba, USNM 37472. Drawn by Louella E. Cable.

Dorsal fin with longest rays reaching to, or more usually beyond, tip of last ray if deflexed, its origin variable, most frequently equidistant between caudal base and tip of snout. Anal originating under or slightly behind base of last dorsal ray, its base 6.5–7.25 in SL. Pelvic inserted nearly an eye's diameter in advance of dorsal and about equidistant between base of pectoral and anal origin, reaching much less than halfway to anal. Pectoral failing to reach pelvic base by about an eye's diameter, 1.7–2.0 in head. Axillary scale of pectoral narrow, failing to reach tip of fin by less than diameter of pupil, 1.9–2.3 in head.

Color. In alcohol, pale. Sides of head silvery. Silvery lateral band distinct, generally nearly as broad as eye; some specimens with dusky punctulations on back extending onto caudal fin.

Size. A total length of about 105 mm (4.2 in.) is attained.

Variation. Certain poorly preserved specimens from Melbourne Beach, Key West, Tortugas, and Pensacola, Florida, in the *Study Material* above, appear to be more or less intermediate between this species and *eurystole*. The gill rakers, which are difficult to count because of the rather small size and poor condition of the specimens, seem to be rather more numerous than in West Indian specimens. The shape of the dorsal, the length of the pectoral, and the size of the eye all agree with specimens from the West Indies, but the position of the anal is rather intermediate.

Range and Habitat. This Anchovy apparently ranges from the West Indies to Florida and the Gulf Coast, and probably to North Carolina. It has been reported for New York (*15*: 42), but none from New York and neighboring states has been available for study. This fish seems to be common, though probably not numerous, in the West Indies. Northward it is apparently only a stray. Most of the specimens studied were taken in shallow water. A few, one from off Melbourne Beach, Florida, and two from Mississippi Sound, Miss., were taken in somewhat deeper water with trawls. It is not known to enter brackish water.

Synonyms and References:

Engraulis perfasciatus Poey, Memorias, *2*, 1860: 312 (orig. descr.; type local. Cuba; type MCZ 17955; cf. several species); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 391 (descr., San Domingo, Cuba; doubtfully distinct from *E. argyrophanus* Cuvier and Valenciennes).

Stolephorus perfasciatus Swain and Meek, Proc. Acad. nat. Sci. Philad. (1884), 1885: 34 (descr., Key West, Florida, and Havana, Cuba); Henshall, Bull. U. S. Fish Comm. (1889), *9*, 1891: 373 (more abund. at Marco than elsewhere in w. Florida); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 441 (descr., range); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20*, 1902: 88 (descr., range, Aguadilla, Puerto Rico); Metzlaar, Bijdr. Dierk. Amst., 1922: 136 (Curaçao, taken with *S. brownii* and *Jenkinsia lamprotaenia*).

Anchovia perfasciata Jordan and Thompson, Bull. U. S. Bur. Fish. (1904), *24*, 1905: 233 (Tortugas, Florida); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 211 (Aguadilla, Puerto Rico); Nichols, New York Acad. Sci., *10* (2), 1929: 204, fig. 34 (diagn., distr., Puerto Rico); Hildebrand, Copeia, 1941: 224 (Beaufort, North Carolina).

Anchoviella perfasciata Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 394 (descr. of "type" from Cuba; range, Florida Keys to Cuba); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 44 (descr., range, New York to Cuba); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 70, fig. (range; strays northward to N. Y.); Fowler, Proc. Acad. nat. Sci. Philad., *82*, 1930: 269 (Grenada, B. W. I.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 47 (range, Florida Keys to Jamaica); Howell-Rivero, Bull. Mus. comp. Zool. Harv., *82*, 1938: 172 (types MCZ 17955; 9 specimens, 82–103 mm, includ. 100-mm specimen as holotype, Poey's No. 422); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 13 (Tortugas, Florida; taxon. notes); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 116, fig. 49 (descr., cf. *A. eurystole*, range).

Doubtful References:

Engraulis argyrophanus Cuvier and Valenciennes, Hist. Nat. Poiss., 1848, *21*: 49 (orig. descr.; type local. "equitorial Atlantic"; cf. *A. hepsetus*; specimen said to have been taken in equatorial Atlantic on a voyage from Europe to Batavia. The specimen, therefore, may not have been taken near America, and the description is too inadequate for positive identification with any American species. Thus it seems inadvisable to use this name. Recent writers generally have referred specimens possessing a short maxillary, taken between New Jersey and Cape Cod, to *argyrophanus*, a procedure that in the light of present knowledge seems to be incorrect).

Stolephorus miarchus Jordan, Proc. U. S. nat. Mus. (1884), *7*, 1885: 106 (Key West, Florida; indistingu. from types of this species; probably young *A. perfasciata*).

Anchovia perfasciata Nichols and Breder, Zoologica, N. Y., *9* (1), 1927: 42, fig. (diagn., vic. of New York City, range; distingu. characters of this species and of *eurystole* [*argyrophanus*] are not stated correctly;

the figure looks somewhat like *perfasciata*; it is the same one used by Nichols [1929: 204] and may have been based on a West Indian specimen).

Negative References:

Stolephorus perfasciatus Swain, Bull. U. S. Fish Comm. (1882), *2*, 1883: 55 (descr. of specimen from Woods Hole, Massachusetts, which was *A. eurystole*); Jordan and Gilbert, Bull. U. S. nat. Mus., *16*, 1883: 272 (descr. of specimen from Woods Hole, Mass., which was *A. eurystole*; West Indies includ. in range, where *eurystole* does not occur); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 217 (descr. of specimens from Noank, Connecticut, and Gravesend Bay, Long Island, N. Y.; specimens, in part at least, exam. by me and found to be *A. eurystole*).

Anchoviella brevirostris (Günther) 1868

Study Material. Two small soft specimens, 26 and 24 mm SL, from Lago Maximus, far up the Amazon Basin, Brazil, and six specimens that have been more or less dry, 17–22 mm SL, from Teffé, also far up the Amazon Basin, which may be of this species, all in MCZ. Another, 40 mm TL, from Lake Rogagua, Bolivia, also may be of this species (part of CAS 9398). Because of the poor condition and small size of the specimens and the inadequacy of the original description, identification is uncertain.

Description. Proportional dimensions in per cent of standard length, based on two of the larger and better specimens, 26 and 24 mm SL, respectively.

Body: depth 15.3, 16.1.
Head: length 20.4, 24.4.
Snout: length 3.8, 4.15.
Eye: diameter 7.7, 7.3.
Postorbital: distance 12.7, 12.5.
Maxillary: length 15.4, 12.5.
Mandible: length 15.4, 13.7.

Anal fin: length of base 19.2, 17.5.
Pectoral fin: length ?, 11.2.

Gill rakers: 13 or 14+19 (4 specimens).
Fin rays: dorsal 12 or 13; anal 16–19; pectoral 11 or 12 (4 specimens).

Body slender, its depth 6.2, 6.5 in SL. Head 4.1, 4.9. Snout projecting about half of its length beyond mandible, 5.5, 6.3 in head. Eye 3.0, 3.2. Postorbital part of head 1.75, 1.9 in head. Maxillary nearly straight, rounded distally, extending about an eye's diameter beyond posterior rim of orbit but not quite to joint of mandible, 1.5, 1.75 in head. Mandible 1.57, 1.6.

Dorsal origin about equidistant between base of caudal and tip of snout. Anal origin under base of last 2 or 3 rays of dorsal; anal base 5.2, 5.7 in SL. Pectoral failing to reach pelvic by an eye's diameter, 2.0 in head.

Color. Very old specimens, in alcohol, faded, except for the silvery lateral band, which is somewhat narrower than the eye.

Digest of Günther's Description, type 87 mm TL. Head 4.5, its depth 5.33. Snout much shorter than eye, projecting only slightly beyond mandible. Eye 3.5 in head.

Maxillary dilated and rounded distally, not extending to joint of mandible. Dorsal origin equidistant between base of caudal and tip of snout. Anal origin below last rays of dorsal. Pectoral ending "a great distance" from the pelvic. Fin rays: dorsal 15, anal 18. Scales 41. Sides with a well-defined silvery band, this band nowhere wider than eye.

It is most unfortunate that the number of gill rakers was not stated.

Range and Habitat. If the specimens examined have been correctly identified and are the same species, the range extends from "Caxoeira,[10] Province of Bahia," Brazil, type locality, to Lago Maximus and Teffé, both far up the Amazon; and probably to Rio Chapare and Lake Rogagua, Bolivia. This species, then, seems to live in fresh water. That its distribution is as wide as indicated remains to be confirmed from the study of more and better specimens.

Synonyms and References:

Engraulis brevirostris Günther, Cat. Fish. Brit. Mus., *7*, 1868: 392 (orig. descr.; type local. "Caxoeira, Province of Bahia," Brazil); Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 411 (refer it to *Amplova*, herein regarded incorrect).

Amplova brevirostris Myers, Proc. Calif. Acad. Sci., *23*, 1940: 440 (notes).

Anchoviella brevirostris Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 119 (descr., range).

Doubtful Reference:

Anchoviella carrikeri Fowler, Proc. Acad. nat. nat. Sci. Philad., *92*, 1940: 73, fig. 28 (orig. descr.; type local. mouth of Rio Chaparé, Cochabamba, Bolivia; type ANSP 68980; placed here with considerable doubt because scales [31–33] and gill rakers on the lower limb [14 or 15] seem to be too few, and the pectoral fin as shown in figure may be too long).

Negative References:

Anchoviella brevirostris Pearson, Indiana Univ. Stud., 64, 1925: 50 (Lake Rogagua, Bolivia; cf. paratype of *Stolephorus guianensis* Eigenmann by Myers and found to be that species; see ref. under *A. guianensis*); Fowler, Proc. Acad. nat. Sci. Philad., *92*, 1940: 94 (listed, after Pearson).

Anchoviella guianensis (Eigenmann) 1912

Figure 47

Study Material. A paratype, 50 mm TL, from the Demerara River, British Guiana, CM 2449; and a rather poorly preserved specimen, 62 mm, from Itacoatiara, Amazonas, Brazil, CNHM 15480.

Distinctive Characters. This species differs from the specimens herein assigned to *A. brevirostris* chiefly in the greater number of gill rakers.

Description. Proportional dimensions in per cent of standard length, and counts, based on *Study Material*, 50 and 62 mm, respectively.

[10] Dr. G. S. Myers has advised that "Caxoeira" and "Cachoeira" are alternative spellings in Brazilian Portuguese for "rapids," and that both are pronounced alike. Cachoeira is the generally accepted spelling today. —Y. H. O.

Body: depth 20, 17.4.
Head: length 23.7, 24.2.
Snout: length 4.5, 5.0.
Eye: diameter 7.5, 7.0.
Postorbital: distance 10.7, 14.2.
Maxillary: length 12.5, 13.3.
Mandible: length 14, 13.8.

Anal fin: length of base 16.8, 15.5.
Pectoral fin: length 15.2, 16.8.

Scales: *ca.* 41, 38.
Gill rakers: 16+22, 17+24.
Fin rays: dorsal 13, 14; anal 18, 19; pectoral 12, 13.

BODY compressed, its depth 5.0, 5.7 in SL. HEAD 4.2, 4.1 in SL, its depth about equal to its postorbital part and half of eye. SNOUT projecting nearly half of its length beyond mandible, 5.3, 4.9 in head. EYE 3.2, 3.5. POSTORBITAL rather short, 2.2, 1.8 in head. MAXILLARY extending about 75% of diameter of eye beyond orbit, but not to joint of mandible, 1.9, 1.8 in head. MANDIBLE 1.7, 1.75. CHEEK broad, very slightly longer than eye, its posterior angle about 60°.

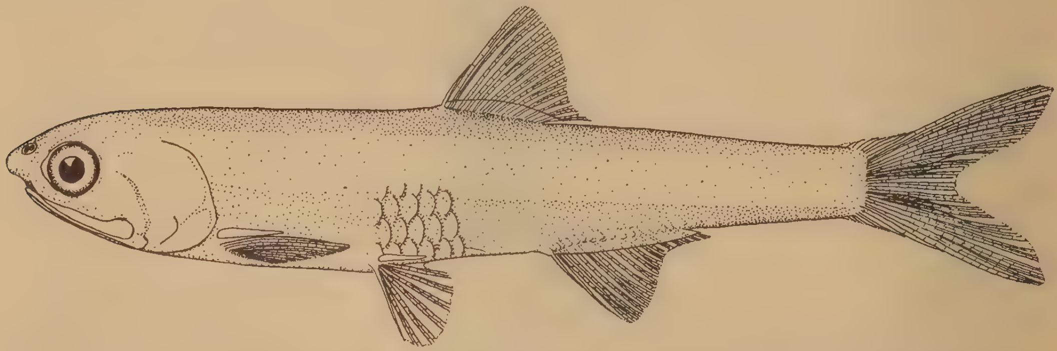

FIGURE 47. *Anchoviella guianensis*, 62 mm TL, from Amazonas, Brazil, CNHM 15480. Drawn by Louella E. Cable.

DORSAL fin with longest rays reaching somewhat beyond tip of last ray if deflexed, its origin equidistant between tip of snout and caudal base. ANAL originating under, or a little in advance of, base of last dorsal ray, its base 5.95, 6.5 in SL. PELVIC inserted equidistant between pectoral base and anal origin. PECTORAL failing to reach pelvic by diameter of pupil, 1.55, 1.45 in head. AXILLARY SCALE of pectoral narrow, reaching well beyond midlength of pectoral, 2.4, 2.45 in head.

Color. In alcohol, pale (probably preserved originally in formalin). Side of head silvery. Pale streak, probably silvery in life, on side. Back with dark punctulations arranged in two more or less definite rows behind dorsal fin; dusky punctulations along base of anal, and a median dark stripe behind anal; paratype with dusky punctulations present also on dorsal, caudal, anal, and upper rays of pectoral.

Range and Habitat. Its range extends from Trinidad, B.W.I., and Venezuela to northern Brazil and the upper Amazon Basin in Bolivia. In addition to the holotype from Bartica Rocks, British Guiana, Eigenmann had paratypes from the Morawhanna and Demerara rivers, British Guiana. It is recorded for La Brea Beach, Trinidad, and for Caño de Guanoco, Venezuela, without comment by Fowler (see reference below). Fresh water seems to be its chief habitat.

Synonyms and References:

Stolephorus guianensis Eigenmann, Mem. Carneg. Mus., 5, 1912: 447, pl. 62, fig. 5 (orig. descr.; type local. Bartica Rocks, British Guiana; type in CM; paratypes from Morawhanna and Demerara rivers, Brit. Guiana).

Anchoviella guianensis Fowler, Proc. Acad. nat. Sci. Philad., *83*, 1931: 392, 406 (La Brea Beach, Trinidad, and Caño de Guanoco, Venezuela); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 122, fig. 52 (synon., descr., relation.); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 48 (refs.).

Anchovia brevirostris Pearson (not of Günther), Indiana Univ. Stud., 11 (64), 1924: 50 (two immatures, 30 and 37 mm, IU 17354, now in CAS, rec. from Lake Rogagua, Bolivia; cf. paratype of *Stolephorus guianensis* Eigenmann by Myers and found to be that species).

Amplova guianensis Myers, Proc. Calif. Acad. Sci., (4) *23*, 1940: 440 (descr., exam. specimens from Morawhanna [paratype]; Lagoa Grande, lower Amazon, near Obidas, Brazil; and Lake "Rogoagua," Bolivia; those from last mentioned place are the ones ident. as *A. brevirostris* by Pearson; see above).

Anchoviella alleni (Myers) 1940

Study Material. The holotype and 6 paratypes, 80–84 mm TL, from Peruvian Amazon drainage system; the holotype and 4 paratypes in CAS, 2 paratypes in USNM.

Distinctive Characters. This species is close to *A. guianensis*, from which it differs in having a somewhat smaller eye, a shorter anal base, a shorter and broader cheek, a longer axillary scale on the pectoral, and in color.

Description. Proportional dimensions in per cent of standard length, and counts, based on the type material noted above, 80–84 mm TL.

Body: depth 18.8–20.
Head: length 22.7–25.
Snout: length 3.4–4.2.
Eye: diameter 5.5–6.25.
Postorbital: distance 11.3–12.
Maxillary: length 11.8–13.
Mandible: length 12.7–13.2.

Anal fin: length of base 13.3–15.
Pectoral fin: length 14.7–16.5.

Scales: *ca.* 44–46.
Gill rakers: 16–18 + 23–26.
Fin rays: dorsal 14 or 15; anal 18 or 19; pectoral 12 or 13.
Vertebrae: 42 (1 specimen).

Body slender, moderately robust, its depth 5.0–5.3 in SL. Head 4.0–4.4 in SL, its depth only slightly less than its postorbital length and eye. Snout projecting about half of its length beyond mandible, 5.5–6.0 in head. Eye 3.7–4.1 in head, 1.9–2.1 in postorbital part of head. Postorbital 1.9–2.0 in head. Maxillary slightly expanded and rounded distally, extending as much as diameter of pupil beyond posterior rim of orbit, failing to reach joint of mandible by about half of diameter of pupil, 1.7–2.0 in head. MANDIBLE 1.63–1.77. CHEEK very short and broad, slightly rounded posteriorly, scarcely as long as eye, and scarcely forming an angle.

DORSAL fin with longest rays reaching to or beyond tip of last ray if deflexed, its origin generally a little nearer to caudal base than to tip of snout. ANAL originating immediately behind vertical from base of last ray of dorsal, its base 6.7–7.4 in SL. PELVIC reaching a little more than halfway to anal, inserted nearer to base of pectoral than to origin of anal by diameter of pupil. PECTORAL moderately falcate, failing to reach pelvic by diameter of pupil, 1.4–1.6 in head. AXILLARY SCALE of pectoral reaching opposite distal third of fin, 2.0–2.2 in head.

Color. In alcohol, pale, probably preserved originally in formalin. Lateral band bright silvery, nearly as broad as eye, bounded above by a dark line. Tip of snout and back with dusky punctulations, these sometimes arranged in two more or less definite rows posterior to dorsal fin. Caudal with dusky markings and sometimes with a broad dusky margin.

Range. Known only from the Peruvian Amazon country, from Lake Cashiboya, and Gosulima Cocha, Upper Rio Morona, Peru, 2,000 miles from the sea.

Synonyms and References:

Amplova alleni Myers, Proc. Calif. Acad. Sci., (4) *23*, 1940: 441 (orig. descr.; type local. Lake Cashiboya, Peru; type CAS 6421; cf. *Stolephorus guianensis* Eigenmann and *Engraulis brevirostris* Günther; paratypes from Lake Cashiboya, Rio Ucayale; Gosulima Cocha, Upper Rio Morona; and Rio Morona, all in Peru); Eigenmann and Allen, Fishes West. S. Amer., Univ. Ky., 1942: 333 (add. specimens from upper Amazon basin).

Anchoviella alleni Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 124, fig. 53 (descr. of type material; cf. *Stolephorus guianensis* Eigenmann).

Anchoviella nattereri (Steindachner) 1879

Study Material. None.

Distinctive Characters. In general, *A. nattereri* seems to be related to *A. blackburni* and *A. lepidentostole*, but it differs from each of them in the rather more numerous anal rays, the more posterior origin of the anal in relation to the dorsal, and the much longer pectoral fin, which overlaps the pelvic.

Description. Based on original account, translated and condensed from Steindachner, of a specimen 50 mm long.[11]

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[11] A description with figure of an anchovy from Iquitos, Peru (upper Amazon Basin), designated *Engraulis iquitensis* by Shoji Nakashima (*14*: 6), shows some of the characters of *A. nattereri*. At least the general shape of the body, the number of anal rays, and the long pectoral overlapping the base of the pelvic seem to agree. However, Nakashima did not describe the maxillary, and its outline is not clearly shown in the figure; the number of gill rakers is not stated; and the description and figure do not agree in several respects. Therefore, it is impossible to place the fish in any genus with a degree of certainty, or to determine the validity of the species. As the author designated no type and failed to compare his fish with any known species, the name probably is without standing and no further reference will be made to it.

Body: depth 4.0.	*Scales*: *ca.* 40.
Head: length 3.33.	*Fin rays*: dorsal 12; anal 28 or 29.

BODY with dorsal profile anterior to dorsal fin less convex than ventral profile. SNOUT reaching well beyond mandible, 4.0 in head. EYE 3.6. MAXILLARY nearly square distally, not quite reaching to joint of mandible. Longest GILL RAKERS about as long as eye.

DORSAL origin slightly nearer to base of caudal than to tip of snout. ANAL origin about under middle of dorsal base. PECTORAL slightly longer than postorbital part of head, reaching middle of pelvic. The silvery lateral band is definitely marked.

Range. Known only from the type from Belém (Pará), Brazil.

Synonyms and References:

Engraulis nattereri Steindachner, Ichthyol. Beitr., 8, 1879: 56 (orig. descr.; type local. Pará, Brazil; cf. *Engraulis surinamensis* Bleeker = *E. edentulus* Cuvier).

Anchoviella nattereri Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 133 (descr. after Steindachner; relation.).

Negative Reference:

Anchovia nattereri Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 413 (descr. based on specimens from Pará, Brazil, MCZ 18044; exam. by me and found to be *Anchovia clupeoides*, differing from Steindachner's descr. of *A. nattereri* in the longer pointed maxillary, in the apparently shorter anal fin and its more posterior origin with respect to dorsal, and in the much shorter pectoral fin, not extending beyond base of pelvic).

Anchoviella pallida (Starks) 1913

Figure 48

Study Material. Three specimens, 72, 80, and 102 mm TL, the first two being the holotype and paratype of *Anchoviella venezuelae* Fowler, the third one, the holotype of *Anchovia pallida* Starks, from Caño de Guanoco, Venezuela, and Pará, Brazil, respectively. The specimens agree so well that they almost certainly are one species.

Distinctive Characters. In general shape this species resembles *Cetengraulis edentulus*; however, it differs from it in lacking a membrane connecting the gill covers across the isthmus, and in having a longer and narrower cheek, a higher dorsal, and a longer pectoral. From the other members of its genus it is well differentiated by the deep body, long head, long pectoral, and numerous gill rakers.

Description. Proportional dimensions in per cent of standard length, and counts, based on the study specimens, 72–102 mm TL.

Body: depth 25.6–28.5.	*Maxillary*: length 19–20.
Head: length 28.5–29.4.	*Mandible*: length 18.8–20.
Snout: length 4.5–4.8.	*Anal fin*: length of base 27.7–28.5.
Eye: diameter 6.36–6.9.	*Pectoral fin*: length 18.8–20.
Postorbital: distance 15.8–17.	

Scales: *ca.* 36–38.
Gill rakers: 28–34 + 36–45.

Fin rays: dorsal 12–14; anal 24–26; pectoral 12 or 13.

Body strongly compressed, its depth 3.5–3.9 in SL. Head 3.4–3.5, its depth equal to its postorbital length and about half of eye. Snout projecting about 0.66 of its length beyond mandible, 6.0–6.4 in head. Eye 4.2–4.9. Postorbital part of head 1.7–1.85 in head. Maxillary somewhat expanded, rounded distally, extending about 1.5 times diameter of eye beyond posterior rim of orbit, not quite reaching joint of mandible, 1.4–1.55 in head. Mandible 1.43–1.55. Cheek narrow, equal to length of snout and eye in large examples, somewhat shorter in smaller ones, its posterior angle about 35°. Gill rakers close-set, numerous, about as long as eye (possibly increasing in number with age).

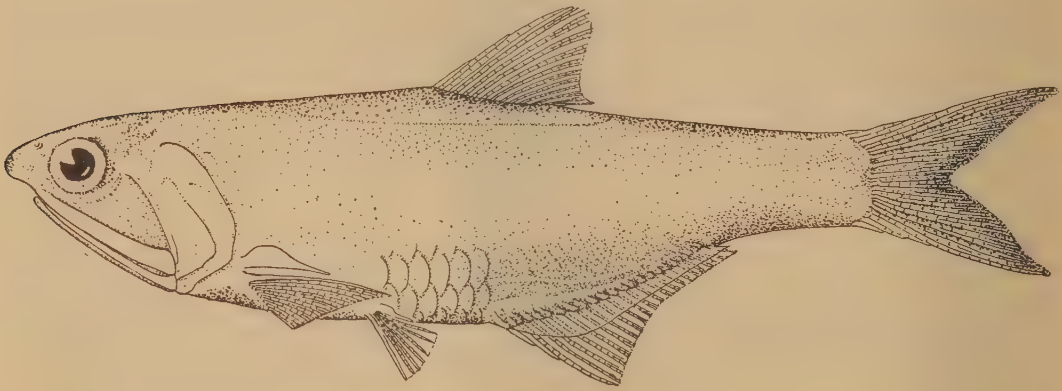

Figure 48. *Anchoviella pallida*, type specimen, 102 mm TL, from Pará, Brazil, SU 22216. Drawn by Alice C. Mullen.

Dorsal fin with longest rays reaching beyond tip of last ray if deflexed, its origin about equidistant between caudal base and tip of snout. Anal originating about under middle of dorsal base, 3.5–3.6 in SL. Pelvic reaching about 0.66 of distance to anal, inserted a little nearer to origin of anal than to base of pectoral. Pectoral reaching beyond base of pelvic by as much as diameter of pupil in largest specimen examined, somewhat shorter in smaller examples, 1.4–1.85 in head. Axillary scale of pectoral broad at base, tapering abruptly, about a third to half as long as the fin, 3.3–3.6 in head.

Color. In alcohol, plain. No silvery lateral band evident. Side of head silvery. Back with dusky punctulations. Caudal fin with a dusky margin in the largest specimen examined (holotype), but not evident in the others.

Variation. The number of gill rakers in the three specimens examined shows a rather wide variation, not attributable to age and size; the smallest specimen, according to my counts, has 34 + 42 rakers (34 + 36 according to Fowler's original description of *A. venezuelae*), the largest 34 + 45, and the intermediate one 33 + 40 on one side and 28 + 36 on the other.

Range. Known from only three specimens, two from Caño de Guanoco, Venezuela, and the type from Pará, Brazil.

Synonyms and References:

Anchovia pallida Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 9, pl 1 (orig. descr.; type local. Pará, Brazil; type SU 22216; cf. *Engraulis endentulus* Cuvier, *E. vaillanti* Steindachner and *Cetengraulis juruensis* Boulenger).

Anchoviella venezuelae Fowler, Proc. Acad. nat. Sci. Philad., *83*, 1931: 406, fig. 6 (orig. descr.; type local. Caño de Guanoco, mouth of Rio San Juan, Venezuela; type ANSP 53322; cf. *Anchovia parva* Meek and Hildebrand).

Anchoviella pallida Fowler, Proc. Acad. nat. Sci. Philad., *93*, 1941: 126 (synon., descr., Ceará, Brazil); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (ref. Brazilian rec.); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 134, fig. 59 (descr., *A. venezuelae* in synon.); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 48 (synon., refs.).

Anchoviella elongata (Meek and Hildebrand) 1923

Figure 49

Study Material. Specimens 65–100 mm: the type material from Mindi, Canal Zone, one specimen from Porto Bello, Panama, and 22 from Puerto Pilon, Panama.

Distinctive Characters. This species is readily recognized by the slender body, the very large eye, and the moderately few anal rays and gill rakers. In the length and shape of the maxillary it approaches the genus *Anchoa* rather closely.

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 14 specimens in *Study Material.*

Body: depth 17.5–20.
Head: length 25.5–27.
Snout: length 4.5–5.1.
Eye: diameter 8.2–9.0.
Postorbital: distance 12.1–13.3.
Maxillary: length 19–20.
Mandible: length 17.8–18.8.

Anal fin: length of base 22–23.7.
Pectoral fin: length 15.3–16.3.

Scales: *ca.* 36–40.
Gill rakers: 17 or 18 + 22–24.
Fin rays: dorsal 13 or 14; anal 22–24; pectoral 12 or 13.
Vertebrae: 39 (2 specimens).

BODY slender, moderately compressed, its depth 5.0–5.7 in SL. HEAD 3.6–3.9 in SL, its depth equal to postorbital part of head and half of eye. SNOUT projecting about half of its length beyond mandible, 5.3–5.8 in head. EYE large, 3.0–3.3 in head. POSTORBITAL part of head 2.0–2.25 in head. MAXILLARY moderately blunt distally, reaching nearly or quite to joint of mandible (approaching the genus *Anchoa* in these respects), extending nearly an eye's diameter beyond posterior rim of orbit, 1.3–1.45 in head. MANDIBLE 1.45–1.5. CHEEK about equal to length of eye, its posterior angle approximately 60°.

DORSAL fin moderately high anteriorly, its longest rays reaching beyond tip of last ray if deflected, its origin about equidistant between caudal base and anterior margin of eye. ANAL originating under or slightly behind middle of dorsal base, its base 4.2–4.5 in SL. PELVIC generally reaching more then halfway to anal, inserted rather nearer to pectoral base than to anal origin. PECTORAL usually extending scarcely to base of pelvic, 1.6–1.75 in head. AXILLARY SCALE of pectoral about half as long as fin, 2.8–3.75 in head.

Color. In alcohol, pale (originally preserved in formalin). Silvery lateral band poorly defined, narrower than eye. Upper surface of head and back with dusky punctulations; dark spots at base of anal, and a median dark line posterior to anal.

Size. The largest specimen in the collection, about 100 mm (4 in.) TL, is the largest individual reported.

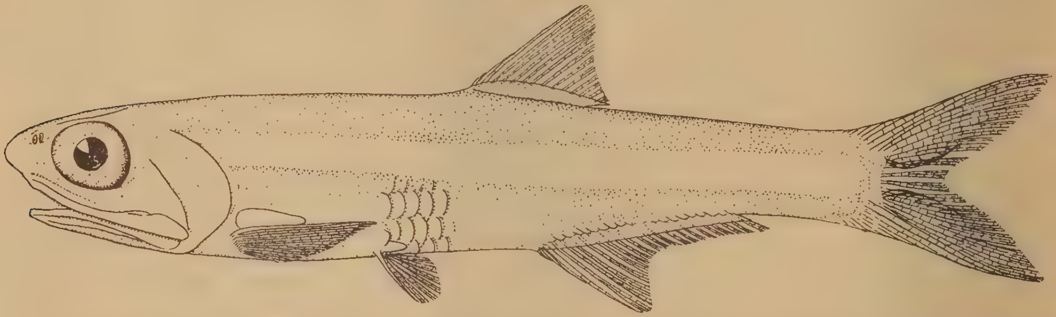

FIGURE 49. *Anchoviella elongata*, 101 mm TL, from Porto Bello, Panama, USNM 82093. Drawn by Louella E. Cable.

Range and Habitat. Known only from the Atlantic coast of Panama, where it apparently is not rare. Specimens have been collected from brackish water at Mindi (near Gatun), and from Gatun Spillway, Canal Zone; and from Porto Bello and Puerto Pilon, Panama.

Synonyms and References:

Anchovia elongata Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 198, pl. 12, fig. 2 (orig. descr.; type local. Mindi, Canal Zone; type USNM 81768; cf. *A. cubana*); Breder, Zoologica, N. Y., *4* (4), 1925: 141 (common at Gatun Spillway, Canal Zone).

Anchoviella elongata Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (ref. to orig. descr.); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 126, fig. 54 (descr., generic relations., range).

Anchoviella lepidentostole (Fowler) 1911

Figure 50

Study Material. The type, about 96 mm (caudal fin damaged), 84 mm SL, and a paratype 76 mm long, 63 mm SL, from "Surinam."

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 84 and 63 mm SL, respectively.

Body: depth 25, 22.2.
Head: length 22.7, 23.8.
Snout: length 3.2, 3.7.
Eye: diameter 6.9, 7.1.
Postorbital: distance 10.7, 11.
Maxillary: length 16.4, 15.
Mandible: length 16.4, 15.8.

Anal fin: length of base 23.8, 23.8.
Pectoral fin: length 16.3, 15.8.

Scales: *ca.* 38.
Gill rakers: 17 + 19 right side, 18 + 20 left side; 17 + 19 both sides.
Fin rays: dorsal 14, 15; anal 25, 23; pectoral 12 (?), 14.

Body rather robust, its depth 4.0, 4.5 in SL. Head 4.4, 4.2 in SL, its depth nearly equal to its length without snout. Snout extending about half of its length beyond mandible, 7.0, 5.5 in head. Eye 3.3, 3.3. Postorbital part of head 2.1, 2.15 in head. Maxillary not quite square distally, scarcely reaching joint of mandible, 1.4, 1.6 in head. Mandible 1.35, 1.5. Cheek as long as eye, the posterior angle about 50°.

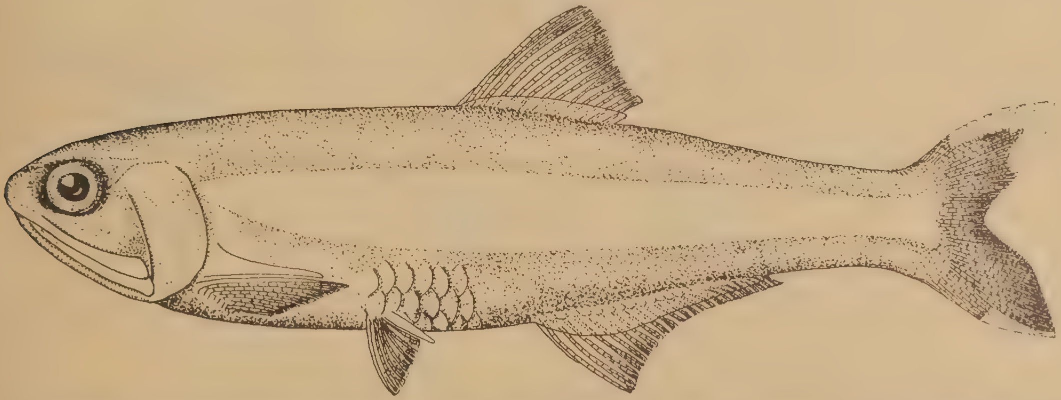

Figure 50. *Anchoviella lepidentostole*, type specimen, 96 mm TL, from "Surinam," ANSP 1346, modified after Fowler (1911: 214, fig. 3). Drawn by Alice C. Mullen.

Dorsal fin with longest rays failing to reach tip of last ray if deflexed, its origin a little nearer to caudal base than to tip of snout. Anal originating under middle of dorsal base, its base 4.2, 4.2 in SL. Pelvic reaching scarcely halfway to anal, inserted a little nearer to anal origin than to pectoral base. Pectoral failing to reach pelvic by diameter of pupil, 1.45, 1.5 in head. Axillary scale of pectoral failing to reach tip of fin by half of diameter of pupil, 2.0, 2.15 in head.

Color. In alcohol, brown. Lower parts silvery. Silvery lateral band strikingly prominent, much wider than eye.

Range. Known only from "Surinam."

Synonyms and References:

Anchovia lepidentostole Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 214, fig. 3 (orig. descr.; type local. "Surinam"; type ANSP 1346; cf. *Engraulis brevirostris* Günther and *E. januarius* Steindachner).

Anchoviella lepidentostole Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (ref. to orig. descr.); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 127, fig. 55 (descr. of type material).

Anchoviella blackburni Hildebrand 1943

Figure 51

Study Material. Type material, 11 specimens, about 33–38 mm TL (caudal fins damaged), all from the Gulf of Venezuela. The specimens probably are not full-grown, but the maxillary, which is shorter and blunter in very young than in adults, probably has acquired the approximate length and shape of a mature fish. At least it is shorter and much more rounded than in specimens of *Anchoa parva* and *A. mitchilli* of similar size.

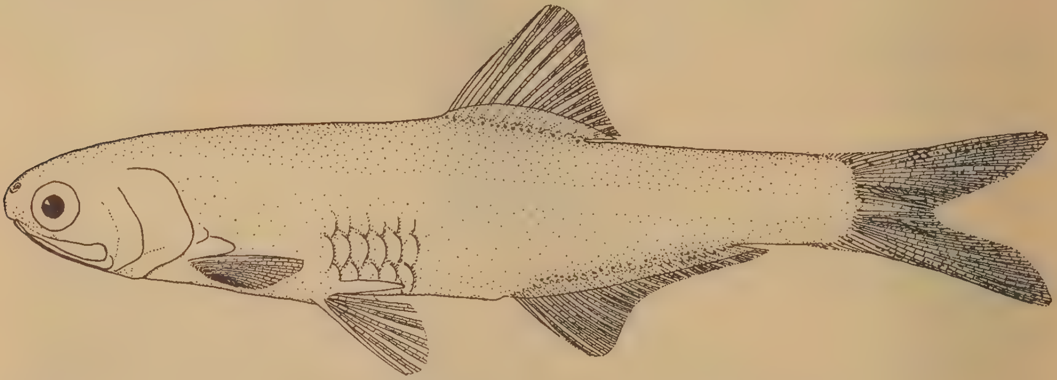

FIGURE 51. *Anchoviella blackburni*, type specimen 35 mm TL, from Gulf of Venezuela, USNM 119793. Drawn by Louella E. Cable.

Distinctive Characters. The long anal fin, the small number of gill rakers, the short head, and the very short, blunt snout distinguish this species from related forms.

Description. Proportional dimensions in per cent of standard length, and counts, based on the 11 type specimens, about 33–38 mm TL.

Body: depth 18.2–20.8.
Head: length 21.7–25.
Snout: length 3.6–3.8.
Eye: diameter 5.0–7.5.
Postorbital: distance 11–14.3.
Maxillary: length 12–15.
Mandible: length 12.3–14.8.

Anal fin: length of base 23.5–26.5.
Pectoral fin: length 13.8–16.6.

Scales: *ca.* 38–41.
Gill rakers: 10–12 + 15–17.
Fin rays: dorsal 13–15; anal 25–27; pectoral 13 or 14.
Vertebrae: 43 (1 specimen).

Body quite strongly compressed, its depth 4.8–5.5 in SL. Head 4.0–4.6 in SL, its depth equal to postorbital part of head and about half of eye. Snout very short, projecting little beyond mandible, about 5.0–7.0 in head. Eye 3.5–4.5. Postorbital part of head 1.6–1.9 in head. Maxillary slightly expanded and rounded distally, extending about half of diameter of eye beyond posterior rim of orbit, not quite to joint of mandible, 1.6–2.0 in head. Cheek only a little longer than eye, the posterior angle about 60°.

Dorsal fin with the longest rays failing to reach tip of last ray if deflexed, its origin about equidistant between caudal base and middle of eye. Anal originating about under origin of second third of dorsal base, its base 3.75–4.25 in SL. Pelvic reaching more than halfway to anal. Pectoral failing to reach base of ventral by somewhat less than diameter of eye, 1.25–1.6 in head.

Color. In alcohol, pale (originally preserved in formalin), with only a suggestion of a narrow silvery lateral band. A row of dark spots along base of anal, continued as a median dark line posterior to anal; a similar row along base of dorsal to upper lobe of caudal.

Range. Known only from the Gulf of Venezuela, where it was taken in Estauques Bay and Jacque Point.

References:

Anchoviella blackburni Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 129, fig. 57 (orig. descr.; type local. Jacque Point, Gulf of Venezuela; type USNM 119793; cf. *Anchoa parva* [Meek and Hildebrand] and *Anchoviella lepidentostole* [Fowler]); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 48 (ref., counts).

Anchoviella (*Amplova*) *jamesi* (Jordan and Seale) 1926

Study Material. Two paratypes, about 47 and 37 mm TL, 36 and 32 mm SL, from fresh water as listed under *Range*; MCZ 17783 and 17784, respectively.

Distinctive Characters. This species has an extremely small mouth for an anchovy and is thus related to *A. balboae* Jordan and Seale of the Pacific coast of Panama, which was made the type of the genus *Amplova* Jordan and Seale, herein regarded as a subgenus. But it differs from *A. balboae* in having fewer anal rays, fewer gill rakers, a more posteriorly placed dorsal fin, and apparently a more slender body. *A. balboae* has 24–27 anal rays and 19–21 + 29–35 gill rakers; its dorsal origin is about equidistant between the base of caudal and middle of eye; and the depth in specimens 75–100 mm TL is 3.5–4.1 in SL.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens 36 and 32 mm SL, respectively.

Body: depth 22.2, 23.8.
Head: length 22.2, 22.7.
Snout: length 3.04, 3.1.
Eye: diameter 5.8, 6.6.
Postorbital: distance ?, 12.8.
Maxillary: length 11.6, 11.9.

Anal fin: length of base 21, 18.7.
Pectoral fin: length 16.6, 18.7.
Scales: *ca.* 40.
Gill rakers: 13+21, 12+20.
Fin rays: dorsal 13, 12; anal 21, 19; pectoral 11, 11.
Vertebrae: 40, ?.

Body moderately compressed, its depth 4.5, 5.3 in SL. Head 4.5, 4.4 in SL, its depth equal to postorbital length and about half of eye. Snout very short, projecting about a third of its length beyond mandible, 7.2, 7.3 in head. Eye 3.8, 3.5. Postorbital part of head 1.85 in head. Maxillary distally rounded, scarcely reaching beyond posterior rim of orbit, and not to articulation of mandible, 2.0, 1.9 in head. Cheek very short and broad, scarcely forming a triangle, much shorter than eye.

Dorsal fin with the longest rays reaching far beyond tip of last ray if deflexed, its origin nearer to base of caudal than to eye. Anal with a prominent lobe anteriorly, its origin slightly in advance of middle of dorsal base, its base 4.8, 5.3 in SL. Pelvic reaching more than halfway to anal, inserted about equidistant between base of pectoral and origin of anal. Pectoral nearly reaching base of pelvic, 1.2, 1.25 in head. Axillary scale of pectoral missing in specimens examined.

Color. Old specimens, in alcohol, faded, pale. Silvery lateral band rather diffuse, narrower than eye.

Range. Known from the type material from fresh water, the holotype being from Jutahy River, the two paratypes from Lago Alexo, Brazil. Two small specimens also are reported from the Rio Ucayali, in Peru.

Synonyms and References:

Amplova jamesi Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 410 (orig. descr.; type local. Jutahy R., Brazil; type MCZ 18014; two paratypes listed from Lago Alexo, Brazil); Myers, Proc. Calif. Acad. Sci., (4) 23, 1940: 441 (descr. after Jordan and Seale; Rio Ucayali, Peru).

Anchoviella jamesi Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 137, fig. 61 (descr., relation. with *Amplova balboae* Jordan and Seale).

Genus *Pterengraulis* Günther 1868

Pterengraulis Günther, Cat. Fish. Brit. Mus., *7*, 1868: 384, 398; type species by monotypy, *Clupea atherinoides* Linnaeus 1758.

Characters. Body rather deep, strongly compressed. Gill rakers short and broad, especially in large examples, only about 11 on upper limb and about 14 on lower limb. Dorsal origin about equidistant between margin of opercle and base of caudal. Pelvic inserted about midway between pectoral base and dorsal origin.

Size. A large size is attained, specimens 250 mm long being included in the collections studied.

Remarks. The anal fin is long, with about 30–33 rays, its origin being under, or more usually in advance of, the dorsal origin. The teeth are small and of nearly uniform size. The maxillary extends to, or nearly to, the joint of the mandible and is rounded distally.

Range. Venezuela to northern Brazil.

Species. Only one, *P. atherinoides.*

Pterengraulis atherinoides (Linnaeus) 1766

Hareng gras Sardinha

Figure 52

Study Material. A total of 20 specimens, 66–250 mm TL, from Caño de Guanoco and Rio Apure, San Fernando de Apure, Venezuela; and from the "Amazon River," Pará, Fortaleza, Cametá, and Ararý, Brazil.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 66–250 mm TL.

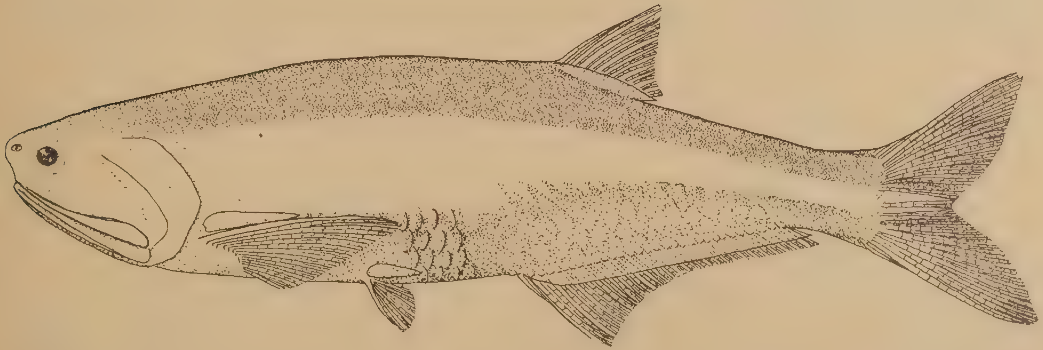

FIGURE 52. *Pterengraulis atherinoides,* 245 mm TL, from "Amazon River," USNM 72551. Drawn by Louella E. Cable.

Body: depth 22–26.
Head: length 22.6–28.5.
Snout: length 2.4–3.1.
Eye: diameter 4.0–5.1.
Postorbital: distance 14.3–16.7.
Maxillary: length 16.5–19.2.
Mandible: length 15.4–18.

Anal fin: length of base 30–34.5.
Pectoral fin: length 20.4–23.7.

Scales: 42–47.
Gill rakers: 10–12 + 12–15.
Fin rays: dorsal 12–14; anal 29–35 (usually 31 or 32); pectoral 13–15.
Vertebrae: 43 and 45 (2 specimens).

BODY strongly compressed, its depth 3.5–4.4 in SL. HEAD 3.8–4.5 in SL, its depth usually equal to its length posterior to middle of eye. SNOUT blunt, 8.0–10 in head. EYE 4.0–6.0. POSTORBITAL part of head moderately long, 1.4–1.55 in head.

MAXILLARY rounded distally, often failing to reach joint of mandible, 1.3–1.5 in head. MANDIBLE 1.3–1.5. CHEEK increasing in proportionate length with growth, much longer than eye and snout in large examples, its posterior angle about 40°.

DORSAL fin with the longest rays reaching beyond tip of last ray if deflexed, its origin about equidistant between caudal base and margin of opercle. ANAL long, its origin under or more usually somewhat in advance of dorsal origin, its base 2.9–3.3 in SL. PELVIC reaching only about a third of distance to anal, usually inserted a little nearer to base of pectoral than to anal origin. PECTORAL reaching to or beyond middle of pelvic, 1.0–1.3 in head. AXILLARY SCALE of pectoral reaching to or somewhat beyond midlength of fin, 1.8–2.1 in head.

Color. In alcohol, pale brownish above. Sides of head and lower parts of body silvery. Silvery lateral band broad anteriorly, narrower on caudal portion of body, becoming diffused with the silvery shade on lower part of body anteriorly in large specimens, apparently persisting posteriorly.

Size. Examples 300 mm TL have been reported.

Commercial Importance. This fish has been reported as very common in the market at Belém (Pará), Brazil.

Range. Its range extends from Venezuela to northern Brazil, possibly as far south as Rio de Janeiro. It ascends streams.

Synonyms and References:

Clupea atherinoides Linnaeus, Syst. Nat., ed. 12, *1*, 1766: 535 (orig. descr.; type local. Surinam; type lost).

Engraulis atherinoides Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 31 (descr., relations., Surinam); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 398 (descr., Surinam, British Guiana, and Pará, Brazil); Steindachner, Ichthyol. Beitr., *8*, 1879: 59 (descr., Surinam; British Guiana; Pará, Cametá, Gurupá, Rio de Janeiro, and Capim R., Brazil).

Pterengraulis atherinoides Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 450 (descr., range); Schreiner and Miranda-Ribeiro, Arch. Mus. nac., Rio de J., *12*, 1903: 94 (range, Guianas to Brazil); Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 10 (common in market at Pará, Brazil); Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 386 (descr., Pará, Cametá, Gurupá, and Ararý, Brazil); Fowler, Proc. Acad. nat. Sci. Philad., *83*, 1931: 407 (Caño de Guanoco, Venezuela); Puyo, Bull. Soc. Hist. nat. Toulouse, *70*, 1936: 170, fig. 36 (descr., habitat in French Guiana); Fowler, Proc. Acad. nat. Sci. Philad., *93*, 1941: 126, fig. 3 (Rio Jaguaribe, Ceará, Brazil; refs.); Arqu. Zool. estad. São Paulo, *3* (6), 1941: 135 (refs., Brazil); Campos, Arqu. Zool. estad. São Paulo, *3* (7) 1941: 200 (synon., descr., range); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 139, fig. 63 (descr., synon., range); Puyo, Faune Emp. Franç., 12, Poiss. Guyane Franç., 1949: 158, fig. 81 (descr., habitat, French Guiana); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 48 (San Fernando de Apure, Venezuela).

Clupea pilchardus de Magalhaes (not of Linnaeus), Monogr. Brazil, Peixes Fluviaes, 1931: 194, fig. 104 (descr., local name, length, habitat).

Doubtful Reference:

Engraulis atherinoides Knerr, "Novara," Zool., Fische (1), 1865: 332 (descr. insufficient for ident.; Rio de Janeiro, Brazil).

Genus *Hildebrandichthys* Schultz 1949

Hildebrandichthys Schultz, Proc. U. S. nat. Mus., *99*, 1949: 49; type species by original designation, *Hildebrandichthys setiger* Schultz.

Characters. Body slender, rather strongly compressed, its depth about equal to postorbital part of head. Head long and low. Eye entirely in anterior half of head. Maxillary rounded posteriorly, not quite reaching joint of mandible. Teeth all small. Gill rakers slender, those at angle of first arch about as long as eye, about 33 on lower limb. Dorsal fin far back, its origin about twice the distance from tip of snout as from caudal base. Anal fin beginning well in advance of origin of dorsal, about 25 rays. Pelvic inserted about equidistant between base of pectoral and anal origin.

Remarks. The numerous long gill rakers and the posterior position of the dorsal fin are the chief distinguishing characters of this genus. *Hildebrandichthys* resembles *Anchovia* in the numerous long, slender gill rakers, but it differs in the very rearward position of the dorsal fin. In the position of the dorsal it tends to agree more or less with *Pterengraulis*, with which it differs in the numerous, long slender gill rakers.

This genus is founded on one species, which in turn is based on only a single small (juvenile) specimen. Though it is quite distinctive, it offers some difficulties because the adult generic characters apparently are not fully developed. The maxillary, for example, is short and rounded, which, so far as known, is true of all young Engraulidae; it may or may not become produced and pointed in the adult, as shown in other generic descriptions.

Range. Known only from the Maracaibo Basin, Venezuela.

Hildebrandichthys setiger Schultz 1949

Figure 53

Study Material. A single small specimen, about 37 mm TL (caudal damaged), 31 mm SL, from the mouth of Rio Caño de Sagua, Lake Maracaibo, Venezuela. This specimen retains some of the juvenile color markings, and the maxillary may not have acquired its adult length and shape.

Distinctive Characters. The numerous gill rakers, which may increase in number with age, in general agree with the rakers in *Anchovia clupeoides*; the posterior position of the dorsal fin calls to mind *Pterengraulis atherinoides*. See also *Remarks* under genus.

Description. Proportional dimensions in per cent of standard length, and counts, based on young specimen, 31 mm SL.

Body: depth 19.2.
Head: length 32.
Snout: length 5.1.
Eye: diameter 8.7.
Postorbital: distance 17.
Maxillary: length 17.
Mandible: length 16.

Anal fin: length of base 22.6.
Pectoral fin: length 12.

Scales: mostly lost, *ca.* 38 pockets.
Gill rakers: *ca.* 23 + 33.
Fin rays: dorsal 12; anal 25; pectoral 13.

Body slender, rather strongly compressed, its depth 5.2 in SL. Head 3.1, its depth about equal to its postorbital length. Snout projecting about 67% of its length beyond tip of mandible, 6.25 in head. Eye small but longer than snout, 3.7 in head. Postorbital length 5.9. Maxillary rounded posteriorly, not quite reaching joint of mandible, 1.9 in head. Mandible 2.0. Cheek a little longer than eye, its posterior angle about 60°. Gill rakers slender, those at angle of first arch about as long as eye (too close-set for accurate counting), about 23 on the upper limb and about 33 on lower limb.

Dorsal fin small, damaged, apparently with a convex margin, the anterior rays not reaching beyond tip of last ray if deflexed, the fin placed very far back, its origin about twice as far from tip of snout as from caudal base. Anal originating about an eye's diameter in advance of dorsal origin and about equidistant between joint of mandible and caudal base, its base 4.4 in SL. Pelvic fin noticeably more than halfway to origin of anal, inserted about equidistant between pectoral base and anal origin, 3.33 in head. Pectoral fin failing to reach base of pelvic by a little less than diameter of eye, 8.4 in SL, 2.6 in head. Axillary scale of pectoral not evident, lost or undeveloped.

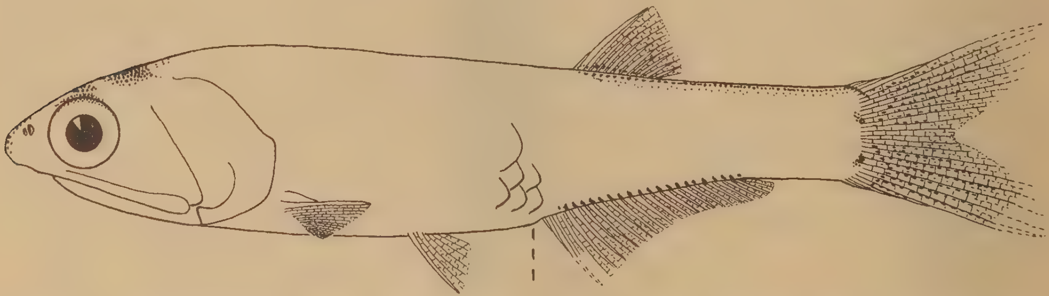

Figure 53. *Hildebrandichthys setiger*, type specimen, 37 mm TL, from Maracaibo Basin, Venezuela, USNM 121779. Drawn by A. M. Awl.

Color. This specimen retains some of the juvenile color markings. In alcohol, rather pale. Side of head and abdomen silvery. A rather faint narrow silvery lateral band present. Dusky dots present on upper surface of head and snout, along base of dorsal, and mostly in two rows behind the dorsal; a series of rather large black dots along base of anal, continued as a single median row behind anal fin (presumably juvenile markings); dusky dots generally distributed over the caudal fin; other fins pale or at most with suggestions of dusky markings.

Range. Known only from the mouth of the Rio Caño de Sagua, Lake Maracaibo, Venezuela.

Reference:

Hildebrandichthys setiger Schultz, Proc. U. S. nat. Mus., *99*, 1949: 49, fig. 7 (orig. descr.; type local. Caño de Sagua, Sinamaica, Venezuela; type USNM 121779).

Genus *Lycengraulis* Günther 1868

Lycengraulis Günther, Cat. Fish. Brit. Mus., 7, 1868: 385, 399; type species *Engraulis grossidens* Cuvier 1828, designated by Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 451.

Characters. BODY slender, compressed, the depth generally less than 27% of SL. MOUTH very large. MAXILLARY extending far beyond eye, generally to or beyond joint of mandible, rounded or pointed distally. MANDIBLE curved upward near tip. GILL RAKERS variable in length, about 10–20+12–25 on first arch. ANAL originating definitely posterior to dorsal origin, with about 24–28 rays. PELVIC inserted about midway between base of pectoral and origin of anal. Young with a silvery lateral band that disappears with age.

Size. About 250 mm is the maximum size attained in this genus.

Remarks. The genus is distinguished by the prominent teeth in the jaws: unequal in size in older specimens but rather even in young; larger in the lower than in the upper jaw, some of them often canine-like; variable in number among the species, about 16–25 enlarged teeth in lower jaw and 40–85 in upper jaw.

Species. Eight species have been recognized, one from the Pacific ranging from Panama Bay to Peru, and seven from the Atlantic ranging from the Gulf of Venezuela to northern Argentina. Five of the Atlantic species come within the scope of the present work.

Key to Species of the Western North Atlantic

1a. Gill rakers long and slender, those at angle equal to or longer than pupil.
  2a. Gill rakers 13–20+17–25 on first arch; cheek scarcely longer than snout and eye in adults.
    3a. Depth of body 23–24.5% of SL; maxillary reaching margin of opercle; pelvic fin usually inserted nearer to origin of anal than to pectoral base, occasionally equidistant between these; vertebrae usually 43 or 44 (occasionally 42 or 45). *grossidens* (Cuvier) 1829, p. 234.
    3b. Depth of body 21–23% of SL in specimens upward of about 100 mm TL; maxillary not reaching margin of opercle; pelvic fin inserted nearer to pectoral base than to anal origin; vertebrae usually 41 (occasionally 42). *limnichthys* Schultz 1949, p. 237.
  2b. Gill rakers 9–13+12–15 on first arch; cheek much longer than snout and eye in adults. *batesii* (Günther) 1868, p. 240.
1b. Gill rakers short and broad, the longest scarcely exceeding half of length of pupil.
  4a. Maxillary sharply pointed distally, extending well beyond joint of mandible; origin of dorsal about equidistant between caudal base and middle of eye; gill rakers 11 or 12+16 or 17. *abbotti* (Fowler) 1915, p. 242.
  4b. Maxillary rounded distally, scarcely reaching joint of mandible; origin of dorsal much nearer to base of caudal than to posterior margin of eye; gill rakers 9–11+12–14. *barbouri* Hildebrand 1943, p. 243.

Table VIII. Comparison of *L. grossidens* with *L. olidus*. Proportional Dimensions in Per Cent of Standard Length.

	L. grossidens 40 specimens & others (40–220 mm TL) from northern Brazil and Venezuela	*L. olidus* 44 specimens (97–240 mm TL) from southern Brazil, Paraguay, Uruguay, and Argentina
Body: depth	21–24.3*	19.2–22.7
Head: length	22.6–26.6	22.2–25
Snout: length	3.3–4.3	2.7–3.4
Eye: diameter	4.8–7.0	4.3–5.7
Postorbital: distance	13–15	13–15.5
Maxillary: length	18.2–21.5	16.5–19.5
Mandible: length	15.2–18.2	15.5–17.5
Anal fin: length of base	23.7–26.5	22–25.5
Pectoral fin: length	16.6–20.0	15.8–17.8

	L. grossidens 40 specimens & others (40–220 mm TL) from northern Brazil and Venezuela	*L. olidus* 44 specimens (97–240 mm TL) from southern Brazil, Paraguay, Uruguay, and Argentina
Scales:	*ca.* 40–44	*ca.* 40–45
Gill rakers:	13–17 + 17–21 (most frequently 14 + 19 or 20)	15–19 + 19–23 (most frequently 16 + 21)
Fin rays:		
dorsal	14 or 15	14 or 15
anal	24–28	26–28
pectoral	14 or 15	14 or 15
Vertebrae:	43 or 44 (4 specimens)	46–48 (3 specimens)

* 23–24.3 in specimens 100 mm upward.

Lycengraulis grossidens (Cuvier) 1829

Sardinha Prata (Brazil)

Figure 54

Study Material. A total of 40 specimens, 40–220 mm TL, and many others as well [presumably from Rio de Janeiro, Brazil and northward, as implied by Dr. Hildebrand under *Relationship and Variation*—Y.H.O.]. Also 44 specimens, 97–240 mm TL, from southern Brazil, Paraguay, Uruguay, and Argentina, representing *L. olidus* (Günther), used as basis for measurements and counts in Tables VIII–X.

Distinctive Characters. See *Relationship and Variation.*

Description. Proportional dimensions and counts, based on 40 specimens from Rio de Janeiro, Brazil, and northward, 40–220 mm TL, in Table VIII.

BODY strongly compressed, increasing in depth with age, its depth 3.85–4.4 in SL in specimens 100 mm or more. HEAD with depth nearly equal to its length without snout, 4.1–4.7 in SL. SNOUT projecting somewhat less than half of its length beyond mandible, 5.6–6.9 in head. EYE 4.2–4.9. POSTORBITAL part of head 1.6–1.7 in head. MAXILLARY little expanded, pointed distally, extending beyond joint of mandible, often nearly to margin of opercle, 1.15–1.25 in head. MANDIBLE 1.33–1.6. CHEEK somewhat longer than eye and snout in large examples, shorter than snout and eye in specimens less than 100 mm, its posterior angle about 35°. GILL RAKERS slender, those at angle fully as long as pupil.

DORSAL fin with the longest rays usually reaching about to tip of last ray if de-

Table IX. Frequency Distribution of Gill Rakers in *Lycengraulis.**

Species	Number of Gill Rakers on Upper Limb of First Arch											
	9	10	11	12	13	14	15	16	17	18	19	20
grossidens	—	—	—	—	4	15	6	7	1	—	—	—
olidus	—	—	—	—	—	—	3	15	8	4	1	3
batesii	3	2	4	5	2	—	—	—	—	—	—	—
abbotti	—	—	1	1	—	—	—	—	—	—	—	—
barbouri	1	3	4	—	—	—	—	—	—	—	—	—

* When the number of counts exceeds the number of specimens reported in the text, the gill rakers were counted on both anterior arches of at least some of the fish.

Table X. Frequency Distribution of Gill Rakers in *Lycengraulis.**

Species	Number of Gill Rakers on Lower Limb of First Arch													
	12	13	14	15	16	17	18	19	20	21	22	23	24	25
grossidens	—	—	—	—	—	1	9	13	15	8	—	—	—	—
olidus	—	—	—	—	—	—	2	5	6	20	7	5	2	1
batesii	—	3	7	2	—	—	—	—	—	—	—	—	—	—
abbotti	—	—	—	—	1	1	—	—	—	—	—	—	—	—
barbouri	1	6	1	—	—	—	—	—	—	—	—	—	—	—

* When the number of counts exceeds the number of specimens reported in the text, the gill rakers were counted on both anterior arches of at least some of the fish.

flexed, its origin rather variable, most frequently nearer to base of caudal than to posterior margin of eye. ANAL with base 3.75–4.2 in SL, its origin generally under middle of dorsal base. PELVIC small, extending much less than halfway to anal, usually inserted nearer to anal origin than to pectoral base. PECTORAL often reaching nearly to base of pelvic, 1.15–1.35 in head. AXILLARY SCALE of pectoral about 0.75 of length of fin, 1.5–1.9 in head.

Color. In alcohol, grayish above. Sides of head and lower 67% of body uniform silvery in adults. Young under 90 mm long with a distinct silvery lateral band narrower than eye, much broader than eye and less distinctly outlined ventrally in specimens 120 mm long, intergrading completely with the silvery color of lower parts of body in somewhat larger individuals. Margin of caudal blackish in adults.

Size. Examples having a maximum total length of 280 mm (11.2 in.) have been reported, but the largest in the collections studied is only 220 mm TL.

Relationship and Variation. L. olidus (Günther) is a very near relative of *L. grossidens*, the two probably intergrading in southern Brazil. If specimens from Venezuela or northern Brazil are compared with examples from extreme southern Brazil, Uruguay, and Argentina, it is at once evident that those from the more southern localities have a more slender and less strongly compressed body, a shorter and less pointed maxillary, smaller teeth in the upper jaw but still much larger than those of other American genera, a greater average number of gill rakers, and more numerous vertebrae. See Table VIII for comparison of *L. grossidens* with *L. olidus.*

L. poeyi of the Pacific coast of Panama is also a near relative of the Atlantic species, but it differs in having: a shorter and blunter snout that projects little beyond the mandible; smaller teeth of more uniform size in the lower jaw; a longer pectoral that reaches to, or a little beyond, the base of the pelvic and has 16 or 17 rays (1 or 2 more than in *grossidens* and *olidus*); and apparently a dark vertebral band, which is missing in the *L. grossidens* and *L. olidus* examined. In depth of body and in length and shape of the maxillary it agrees with *L. olidus* rather than with *L. grossidens*.

Commercial Importance. As some of the specimens in the collections studied were purchased in markets, this species must be of some commercial value.

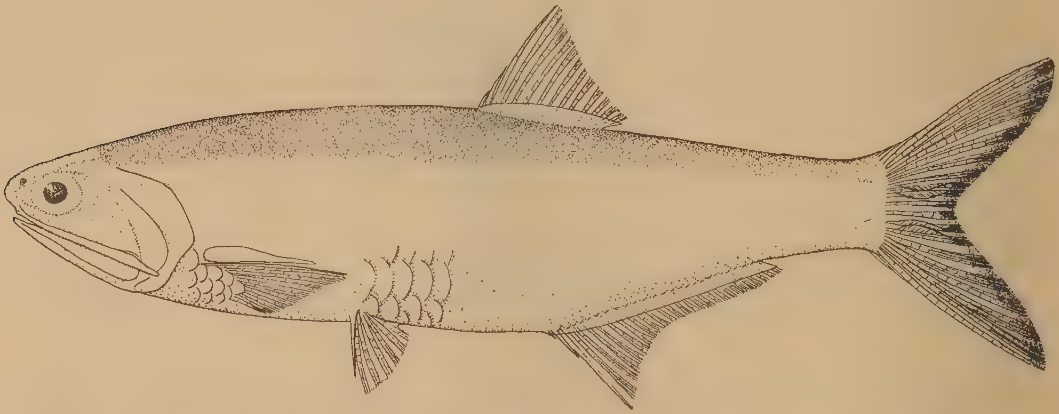

FIGURE 54. *Lycengraulis grossidens*, 214 mm TL, from Porto Inhauna, Brazil, USNM 100835. Drawn by Louella E. Cable.

Range and Habitat. The range of *L. grossidens* extends from the Gulf of Venezuela south about to Rio de Janeiro, Brazil, and of *L. olidus* from southern Brazil to northern Argentina; both species ascend freshwater streams. The rather numerous records of *L. grossidens* from Uruguay and Argentina are apparently referable to *L. olidus*.

Synonyms and References:

Engraulis grossidens Cuvier, in Spix and Agassiz, Pisc. Brazil., 1829: 50, pl. 24, fig. 1 E (orig. descr.; type local. Rio de Janeiro, Brazil); Günther, Cat. Fish. Brit. Mus., 7, 1868: 399 (descr., synon., British Guiana).

Engraulis janeiro Agassiz, in Spix and Agassiz, Pisc. Brazil., 1829: pl. 24, fig. 1 (type local. Rio de Janeiro, Brazil; name and fig. only).

Engraulis dentex Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 28 (orig. descr.; type local. Rio de Janeiro, Brazil); Kner, Reise "Novara," Zool., Fische, *1*, 1865: 332 (descr., Rio de Janeiro); Steindachner, Ichthyol. Notiz., 6, 1867: 35 (descr., Rio de Janeiro and La Plata; the latter undoubtedly referable to *L. olidus*).

Lycengraulis grossidens Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 451 (descr., range, synon.); Gilbert, Proc. Wash. Acad. Sci., *2*, 1900: 163 (descr., Pernambuco, Brazil); Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 11 (descr., Natal, Brazil); Jordan and Gilbert, Bull. Mus. comp. Zool. Harv., *67*, 1926: 383 (descr., Brazil and Uruguay; those from south of Rio de Janeiro, Brazil, probably *L. olidus*; those from Rio Poty, Brazil, are *L. barbouri*); von Ihering, Rev. Indust. Anim., Anno 1 (3), 1930: 233 (size, diagn.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 51 (range, synon.); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 135 (refs., Brazil); Hildebrand, Bull. Bingham oceanogr.

Coll., *8* (2), 1943: 143, fig. 64 (descr., range, synon.); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 54 (synon., refs.).

Negative References:

Lycengraulis grossidens Berg, An. Mus. nac., Buenos Aires, *4*, 1895: 21 (fairly abund. in markets, Buenos Aires and Montevideo; *L. olidus*); Devincenzi, An. Mus. nac., Montevideo, *2* (5), 1924: 189 (*L. olidus*); Thompson, Proc. U. S. nat. Mus., *50*, 1916: 405 (numerous from Montevideo, two from Buenos Aires; in part *L. olidus*).

Lycengraulis limnichthys Schultz 1949

Figure 55

Study Material. Type material of many specimens, 24–150 mm TL, 20–116 mm SL, from Lake Maracaibo, Venezuela, and the lower parts of its tributary streams.

Distinctive Characters. This species is related to *L. grossidens* and *L. olidus*, the latter being extralimital from southern Brazil to Argentina. *L. limnichthys* differs from *grossidens* in having a more slender and apparently less strongly compressed body, specimens of nearly equal size compared. In *limnichthys* the maxillary is a little shorter, scarcely reaching beyond the joint of the mandible and not to the margin of the opercle, whereas in adults of *grossidens* it is longer, reaching well beyond the joint of the mandible and often to the margin of the opercle. In *limnichthys* the pelvic fins are inserted nearer to the base of the upper pectoral ray than to the anal origin, whereas in *grossidens* they are equidistant between these two points, or more usually nearer to the anal origin. And *limnichthys* differs from both *grossidens* and *olidus* in having fewer vertebrae.

Description. Propertional dimensions in per cent of standard length, and counts, based on at least 11 study specimens.

Body: depth 21–23, in specimens 90 mm TL and upward.
Head: length 23–25.
Snout: length 3.0–4.15.
Eye: diameter 5.4–6.5.
Postorbital: distance 12.5–15.
Maxillary: length 17.2–19.2.
Mandible: length 16.3–18.5.
Anal fin: length of base 21–23.5.
Pectoral fin: length 16–19.
Scales: *ca.* 35–45.
Gill rakers: 15–18 + 20–23 (rarely 24 or 25).
Fin rays: dorsal 13–16; anal 23–25 (rarely 26 or 27); pectoral 14 or 15 (rarely 13).
Vertebrae: 41 or 42 (11 specimens).

Body moderately compressed, its depth 4.35–4.75 in SL in specimens 73–116 mm SL. Head 4.0–4.35, its depth slightly exceeding its postorbital length. Snout blunt, extending about a third of its length beyond tip of mandible, 6.1–7.0 in head. Eye 3.6–4.5. Postorbital length 6.65–8.0 in SL, 1.6–1.8 in head. Maxillary scarcely pointed, extending somewhat beyond joint of mandible in the large examples but not to margin of opercle, 1.25–1.35 in head. Mandible 1.27–1.4. Cheek moderately short and broad, generally about as long as snout and eye, its posterior angle about 30°. Gill rakers moderately slender, those at angle of first arch about as long as pupil, rather spinulose along inner margin, scarcely expanded at tip.

Dorsal fin with longest rays not reaching tip of posterior ray if deflexed, its margin generally slightly concave, its origin usually about equidistant between posterior margin of eye and base of caudal. Anal with a definite lobe anteriorly, its base 4.25–4.75 in SL, its origin about under middle of dorsal base and equidistant between pectoral base and caudal base, or a little nearer to the former. Pelvic generally extending a little less than halfway to anal, inserted somewhat nearer to pectoral base than to origin of anal, 2.4–2.8 in head. Pectoral reaching to or a little beyond base of pelvic in small specimens, frequently failing to reach pelvic in large ones, 1.25–1.4 in head. Axillary scale of pectoral variable in length, reaching somewhat beyond midlength of pectoral to beginning of its distal fourth, 1.4–2.25 in head.

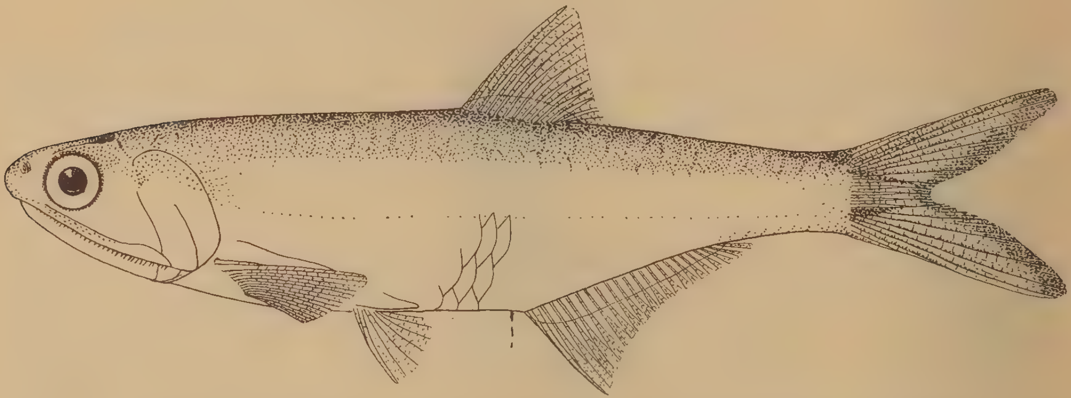

Figure 55. *Lycengraulis limnichthys*, type specimen, from Rio Agua Caliente, above Maracaibo Basin, Venezuela, USNM 121751. Drawn by A. M. Awl.

Color. Back pale, with a median dark streak, much more distinct in some specimens than in others. Sides with a broad silvery lateral band in adults, becoming diffused with the silvery color on the lower part of side in large examples, quite narrow in young. Dorsal and caudal fins with dusky punctulations, the margin of the latter much darker in some specimens than in others; other fins plain. Peritoneum silvery.

Size. The largest example in the collection studied is 150 mm TL and 116 mm SL, which may be near the maximum size attained.

Development. The smallest, 19 mm SL, is slender and has all fins well developed. The caudal fin is as deeply forked as that in the adult, and the other fins have acquired approximately the same shape and relative position as those in adults. The snout remains shorter and projects less strongly beyond the mandible than in larger specimens; the maxillary, also much shorter and rounder, fails to reach the joint of the mandible; and the teeth in the jaws are scarcely evident.

The juvenile color of this same specimen and of others of about equal size consists of a few dark dots over the nostrils, a group of similar dark dots at the occiput, and more or less definite rows on the back. Scattered dark points, present at and on the base of the caudal, extend prominently on the outer rays of the fin, which already has a dusky margin that remains throughout life. A series of prominent black spots along each side of the anal base continues in a single series on the peduncle behind the anal; a few scattered dark dots are present on the side of the head and on the isthmus. This small example, then, is definitely beyond the larval stage and is perhaps a young adult.

The juvenile is slender, as is usual among clupeid fishes. In three specimens, 19, 19.5, and 20 mm SL, the depth is respectively 9.0, 9.5, and 9.3 times in SL; in a group of six, ranging between 27–33 mm SL, the proportionate depth already has increased and is 8.5–6.5 in SL; and in an additional group of five, 32–50 mm SL, the depth is 6.5–5.45 in SL. Measurements of larger fish indicate that the body tends to become proportionately deeper as long as the fish grows.

The teeth in the jaws are well developed but remain minute in specimens around 25 mm SL. They do not become large (for an anchovy) and unequal in size (the chief distinguishing characters of *Lycengraulis*) until the fish attains about 65 mm SL.

In fish 25 mm SL, the snout already projects well beyond the mandible, about as in the adult, and the maxillary is now somewhat pointed and reaches to a point approximately opposite the joint of the mandible. The axillary scale of the pectoral, not detected in the smaller specimens described, is now evident and reaches about to the midlength of the pectoral; this axillary process, though rather variable in length, reaches far beyond the midlength of this fin in adults, generally to or beyond the beginning of its distal third.

The juvenile color markings are retained about as described for the 19-mm fish until a standard length of at least 40 mm is attained. Even then the juvenile markings remain in large part. However, the sides of the head and the abdomen, in part, have become silvery. A very narrow indistinct silvery lateral band has become evident, and this increases rapidly in proportionate width, being prominent and as broad as the eye in specimens of about 75 mm SL; in examples of about 85 mm SL, the band is much broader than the eye, and its lower margin generally has become indefinite. In still larger specimens it usually has become diffused with the silvery color on the lower part of the side. The dark dots along the base of the anal persist longer than any of the other juvenile markings and are visible in half-grown fish; in fact, they are visible in some specimens up to 90 mm SL.

Spawning. Several females with large eggs were taken in Lake Maracaibo on May 16 (1942), indicating that at least some spawning takes place in the spring of the year.

Range. Known only from Lake Maracaibo and from the lower sections of tributary streams, in fresh to slightly brackish water.

Reference:

Lycengraulis limnichthys Schultz, Proc. U. S. nat. Mus., *99*, 1949: 51, fig. 8 (orig. descr.; type local. Rio Agua Caliente, above Lake Maracaibo, Venezuela; type USNM 121751).

Lycengraulis batesii (Günther) 1868

Figure 56

Study Material. A total of 13 specimens, 35–185 mm TL, the larger ones from Brazil, the smaller ones from Venezuela; also 4 juveniles, 21–31 mm TL, from Venezuela.

Distinctive Characters. The slender body, the long narrow cheek, and the rather few and moderately long gill rakers distinguish this species. The statement in the original description, "Gill rakers very short, like tubercles," has been misleading, for they are fully half of the length of eye, a point that was verified from type specimens by J. R. Norman. This statement became especially bothersome upon the discovery of other species that had notably shorter gill rakers.

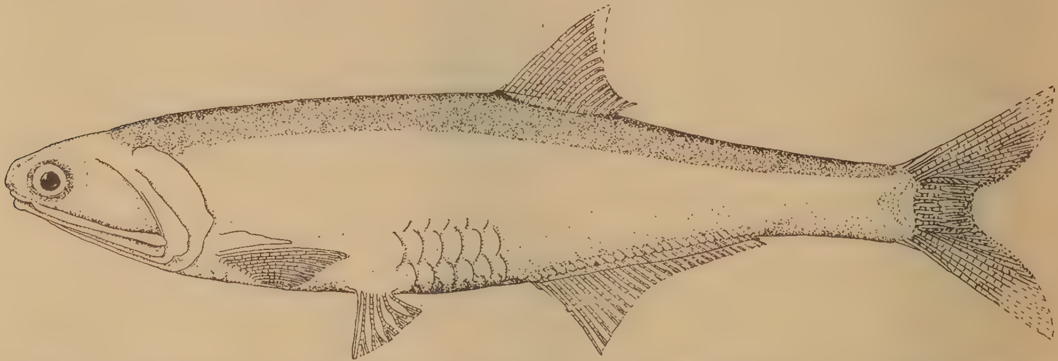

FIGURE 56. *Lycengraulis batesii*, 185 mm TL, 155 mm SL, from Teffé, Brazil, MCZ 18006. Drawn by Alice C. Mullen.

Description. Proportional dimensions in per cent of standard length, and counts, based on the *Study Material.*

Body: depth 16.5–19.
Head: length 21–23.
Snout: length 2.75–3.3.
Eye: diameter 4.2–4.6.
Postorbital: distance 14.3–15.6.
Maxillary: length 17.5–18.2.
Mandible: length 16.1–18.2.

Anal fin: length of base 25–26.2.
Pectoral fin: length 15.4–18.8.

Scales: *ca.* 41–45.
Gill rakers: 9–13 + 12–15.
Fin rays: dorsal 13–15; anal 26–28; pectoral 13 or 14.
Vertebrae: 47 (2 specimens).

BODY slender, compressed, its depth 5.25–6.0 in SL. HEAD 4.3–4.7 in SL, its depth about equal to its postorbital length. SNOUT projecting much less than half of its length beyond mandible, 7.0–8.0 in head. EYE 4.5–5.4. POSTORBITAL part of head 1.4–1.6 in head. MAXILLARY slightly expanded, scarcely pointed, reaching nearly or quite to joint of mandible, 1.2–1.3 in head. MANDIBLE 1.27–1.4. CHEEK in large examples much longer than snout and eye, proportionately shorter in small specimens, its posterior angle about 35°. GILL RAKERS at angle fully half of length of eye.

DORSAL fin with the longest rays extending nearly or quite to tip of last ray if deflexed, its origin much nearer to base of caudal than to eye. ANAL base 3.8–4.0 in SL, its origin slightly in advance of middle of dorsal base. PELVIC failing to reach halfway to anal in adults, extending farther back in young, inserted nearer to pectoral base than to anal origin. PECTORAL scarcely reaching pelvic in adults, rather longer in young, 1.25–1.5 in head. AXILLARY SCALE of pectoral about 67% of length of fin, 2.3–2.7 in head.

Color. Old specimens, in alcohol, grayish above. Side of head and lower 66% of body bright silvery. Small specimens with a broad silvery lateral band and a dark vertebral band. The original description mentioned "an oblong blackish patch on lower half of the end of the tail," but such a blackish patch is not present on the specimens studied.

Size. A total length of at least 185 mm (7.4 in.) is attained.

Development. The juvenile, as in other herring and herring-like fishes, is more slender but rounder than the adult. All juveniles show externally the convoluted intestine, which apparently has not become fully covered by the abdominal wall. The snout is very short and blunt, and in the smallest specimen it scarcely projects beyond the tip of the mandible. The blunt maxillary extends little beyond the posterior margin of the eye. Both anal fin and vent move forward with age; the anal fin has its origin under the posterior rays of the dorsal in a 21-mm specimen, about under the middle of the dorsal base in a 31-mm fish, and in advance of the middle of the dorsal, as in the adult, in a 35-mm fish.

The smallest fish has a dark line on the isthmus and chest, dark dots along the base of the anal, and a single continuous dark median ventral line on the caudal peduncle. The dark line on the isthmus and chest disappears at a length of about 30 mm, but the markings at the base of the anal and on the peduncle remain until a length of at least 52 mm is attained. The dark vertebral band, described for larger fish, first becomes partially evident at a length of about 32 mm. There is no indication of a silvery lateral band up to a length of 52 mm.

Range and Habitat. This species is known from Rio Apure (a tributary of the Orinoco) at San Fernando de Apure, Venezuela; in Brazil it has been taken from the Pará River, from Teffé on the Solimões River, and from the Jutahy River, the last two streams being tributaries of the Amazon.

Synonyms and References:

Engraulis batesii Günther, Cat. Fish. Brit. Mus., 7, 1868: 399 (orig. descr.; type local. Pará R., Brazil; types in BMNH).

Lycengraulis batesii Jordan and Seale, Bull. Mus. comp. Zool. Harv., 67, 1926: 385 (descr. not based on *batesii* throughout; 21 gill rakers on lower limb given whereas *batesii* has only 12–15; Rio Grande, Teffé, Jutahy [River] and Doce R., all in Brazil; Rio Grande specimen is *olidus*, the Doce R. specimen *schroederi*); von Ihering, Rev. Industr. Anim., Anno 1 (3), 1930: 233 (locals., diagn.); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 148, fig. 67 (descr., range); Schultz, Proc. U. S. nat. Mus., 99, 1949: 51 (ref.).

Negative Reference:

Lycengraulis batesii Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 11 (specimen from market at Pará, Brazil, is *L. barbouri* Hildebrand).

Lycengraulis abbotti (Fowler) 1915

Figure 57

Study Material. The type and only specimen known, 180 mm long, from Port-of-Spain, Trinidad.

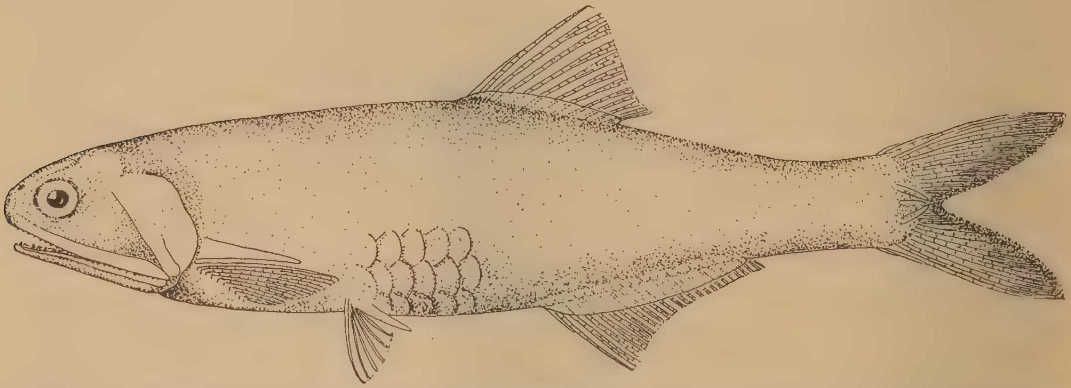

FIGURE 57. *Lycengraulis abbotti*, type specimen, 180 mm TL, from Port-of-Spain, Trinidad, modified after Fowler, (1915: 523, fig. 1), ANSP 45079. Drawn by Alice C. Mullen.

Distinctive Characters. This fish is related to *L. barbouri*, having similar short spiny gill rakers, but it differs in the number of gill rakers, the longer and more pointed maxillary, and the more anterior position of the dorsal fin.

Description. Proportional dimensions in per cent of standard length, and counts, based on the type, 180 mm TL.

Body: depth 27.
Head: length 23.5.
Snout: length 3.37.
Eye: diameter 4.95.
Postorbital: distance 14.8.
Maxillary: length 21.
Mandible: length 18.3.

Anal fin: length of base 25.6.
Pectoral fin: length 18.2.

Scales: *ca.* 37.
Gill rakers: 12+16 and 11+17, including rudiments.
Fin rays: dorsal 13; anal 25; pectoral 16.

BODY fairly robust, its depth 3.7 in SL. HEAD 4.25 in SL, its depth scarcely less than its length without snout. SNOUT projecting less than half of its length beyond mandible, 7.0 in head. EYE 4.8. POSTORBITAL part of head 1.6 in head. MAXILLARY pointed, extending nearly to margin of opercle, 1.13 in head. MANDIBLE 1.3. CHEEK much longer than snout and eye, its posterior angle about 30°. GILL RAKERS short, broad, very spinose, partly rudimentary, none exceeding half of diameter of pupil.

DORSAL fin with the longest rays not quite reaching tip of last ray if deflexed, its origin equidistant between base of caudal and middle of eye. ANAL origin slightly in advance of middle of dorsal base, its base 3.9 in SL. PELVIC reaching less than halfway to anal, inserted nearer to base of pectoral than to origin of anal. PECTORAL not quite reaching base of pelvic, 1.3 in head. AXILLARY SCALE of pectoral fully 75% of fin, 1.8 in head.

Color. Grayish above. Sides silvery. No lateral band. Caudal with a narrow dark margin.

Range. Known only from the type taken at Port-of-Spain, Trinidad.

Synonyms and References:

Anchovia abbotti Fowler, Proc. Acad. nat. Sci. Philad., 1915: 522, fig. 1 (orig. descr.; type local. Port-of-Spain, Trinidad; type ANSP 45079; cf. *Stolephorus surinamensis* Bleeker = *Engraulis edentulus* Cuvier).

Anchoviella abbotti Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 50 (name, local.).

Lycengraulis abbotti Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 150, fig. 68 (cf. *L. barbouri* Hildebrand and *L. schroederi* Hildebrand).

Lycengraulis barbouri Hildebrand 1943

Figure 58

Study Material. Type material, 3 specimens 237, 230, and 205 mm long, from the Rio Poty, Brazil, and a fourth specimen, 220 mm long, from the fish market at Pará; holotype and one paratype, MCZ 35277 and 18017, respectively; second paratype USNM 118997; and fourth specimen SU 22086.

Distinctive Characters. This species differs from *L. batesii* in having a deeper body, a somewhat more posteriorly placed anal fin, and much shorter and broader gill rakers; however, the rakers are about equal in number in the two species. *L. schroederi* Hildebrand, known only from Rio Doce in southern Brazil, is another related species; it has more numerous but equally short, broad, spiny, partly rudimentary gill rakers (17 or 18 + 21 or 22 on the first arch), a larger eye, about 4.9 in head, and a more posteriorly placed anal, its origin under the posterior third of dorsal base.

Description. Proportional dimensions in per cent of standard length, and counts, based on the four study specimens, 205–237 mm.

Body: depth 21.2–23.2.
Head: length 22–25.5.
Snout: length 2.75–3.0.
Eye: diameter 4.25–4.45.
Postorbital: distance 14.5–17.7.
Maxillary: length 18.2–21.
Mandible: length 17.5–20.8.

Anal fin: length of base 24.3–26.2.
Pectoral fin: length 17–18.2.

Scales: *ca.* 40–45.
Gill rakers: 9–11 + 12–14.
Fin rays: dorsal 14 or 15; anal 26–28; pectoral 14 or 15.

BODY rather strongly compressed, its depth 4.3–4.7 in SL. HEAD 3.9–4.5 in SL, its depth about equal to its postorbital length. SNOUT projecting much less than half of its length beyond mandible, 7.8–9.2 in head. EYE 5.0–5.8. POSTORBITAL part of head 1.37–1.5 in head. MAXILLARY rounded distally, scarcely reaching joint of mandible, 1.2 in head. MANDIBLE 1.2–1.27. CHEEK narrow, its length nearly twice snout and eye, its postorbital angle about 30°. GILL RAKERS short, flat, the longest not more than half of length of pupil.

DORSAL fin with the longest rays extending to, or a little beyond, tip of last ray if deflexed, its origin about equidistant between base of caudal and upper anterior angle of gill openings. ANAL with a rather prominent lobe anteriorly, its origin under, or somewhat in advance of, middle of dorsal base, its base 3.8–4.1 in SL. PELVIC reaching much less than halfway to anal, inserted somewhat nearer to base of pectoral than to origin of anal. PECTORAL reaching to, or slightly beyond, base of pelvic, 1.3–1.4 in head. AXILLARY SCALE of pectoral about 75% of length of fin, 1.95–2.1 in head.

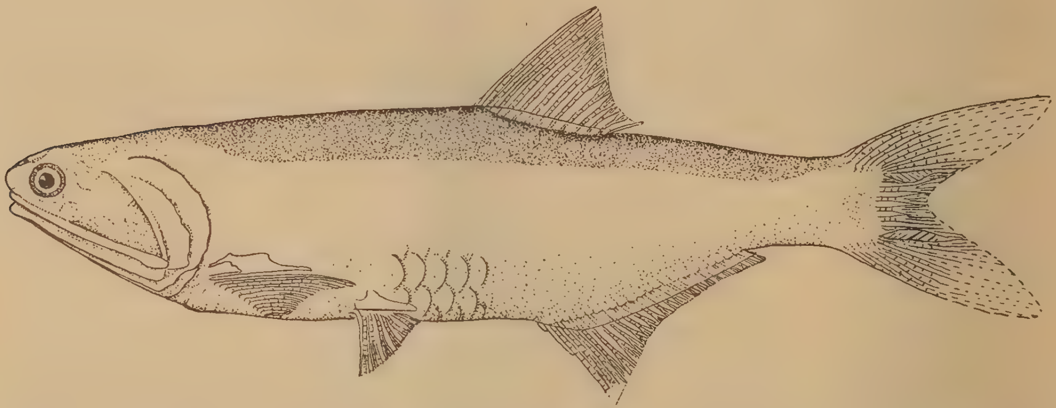

FIGURE 58. *Lycengraulis barbouri*, type specimen, 290 mm TL, 237 mm SL, from Rio Poty, Brazil, MCZ 35277. Drawn by Alice C. Mullen.

Color. Old specimens, in alcohol, grayish above. Lower 75% of body and head plain silvery. Fins unmarked, except for an indication of a black margin on caudal.

Range and Habitat. Known only from northern Brazil, from the Rio Poty, a tributary of the Rio Parnahyba, and from the Belém (Pará) market. [That this species was obtained in the Belém market, far removed from Rio Poty, seems to indicate that the species may well be marine.—Y. H. O.]

Synonyms and References:

Lycengraulis batesii Starks (not of Günther), Stanf. Univ. Publ., Univ. Ser., 1913: 11 (specimen from Pará, Brazil; found to be *L. barbouri*).

Lycengraulis grossidens Jordan and Seale (in part not of Cuvier), Bull. Mus. comp. Zool. Harv., *67*, 1926: 383 ("Rio Puty" = Rio Poty, Brazil; specimens are *L. barbouri*).

Lycengraulis barbouri Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 151, fig. 69 (orig. descr.; type local. Rio Poty, tributary of Rio Parnahyba, Brazil; type MCZ 35277; cf. *L. batesii*).

Genus *Cetengraulis* Günther 1868

Cetengraulis Günther, Cat. Fish. Brit. Mus., 7, 1868: 383; genotype *Engraulis edentulus* Cuvier, first designated by Jordan and Evermann, Bull. U. S. Nat. Mus., 47 (1), 1896: 450.

Characters. BODY rather deep in adults but much more slender in young, quite strongly compressed. MAXILLARY short, distally rounded or very bluntly pointed, usually extending about to articulation of mandible. TEETH in jaws all very small (apparently not disappearing with age as has been stated). GILL RAKERS long, close-set, numerous, increasing with age (about 25 on lower limb in small specimens to about 60 in large ones). PELVIC inserted under, or a little in advance of, dorsal origin. Silvery lateral band present only in specimens about 100 mm TL or less.

Remarks. Gill covers connected across the isthmus by a thin transparent membrane (easily torn); narrow in very young.

Range. The genus is represented on the Atlantic side by two species, ranging from the West Indies to southern Brazil, and on the Pacific side by one species, *C. mysticetus*, known from the Gulf of California to Peru.

Key to Atlantic Species

1a. Depth of body 3.0–3.4 in length; head 4.6–5.3; eye 3.7–4.6 in head; pectoral failing to reach base of pelvic. *edentulus* (Cuvier) 1829, below.

1b. Depth of body 5.0 in length; head 3.5; eye 5.5 in head; pectoral reaching a little beyond base of pelvic. *juruensis* Boulenger 1898, p. 247.

Cetengraulis edentulus (Cuvier) 1829

Bocón (Cuba)

Figure 59

Study Material. About 70 specimens, mostly small, 35–160 mm TL; from Puerto Rico; Jamaica; Cuba; and New Grenada; Colón, Panama; Gulf of Venezuela; Rio de Janeiro, "Barro Santas," "Sambaia," and Cachoeira, Brazil.

Distinctive Characters. See Key to Atlantic Species, above.

Description. Proportional dimensions in per cent of standard length, based on 20 specimens, 70–160 mm, and most of the counts on many more.

Body: depth 25–34.4.
Head: length 30–34.5.
Snout: length 3.8–4.75.
Eye: diameter 6.5–8.0.
Postorbital: distance 18.2–21.2.
Maxillary: length 17.2–19.
Mandible: length 17.3–18.5.
Anal fin: length of base 21.5–23.
Pectoral fin: length 13.3–16.7.

Scales: *ca.* 40–43.
Gill rakers: *ca.* 30+36 in specimens around 65 mm, about 52+55 in specimens about 130 mm TL.
Fin rays: dorsal 14–16; anal 23–26; pectoral 14 or 15.
Vertebrae: 42 (3 specimens).

Body strongly compressed, the ventral outline much more strongly convex than the dorsal outline, the depth increasing with age, 2.9–3.3 in SL in specimens 75 mm TL and upward. Head 3.0–3.5 in SL. Snout quite pointed, extending nearly its full length beyond mandible, 5.5–8.0 in head. Eye 3.7–4.8. Postorbital part of head 1.55–1.75 in head. Maxillary bluntly pointed or rounded distally, 1.72–1.8 in head. Mandible 1.67–1.73. Cheek nearly or quite as long as snout and eye, its posterior angle narrow, about 30°. Gill rakers long, slender, close-set, increasing greatly in number with age.

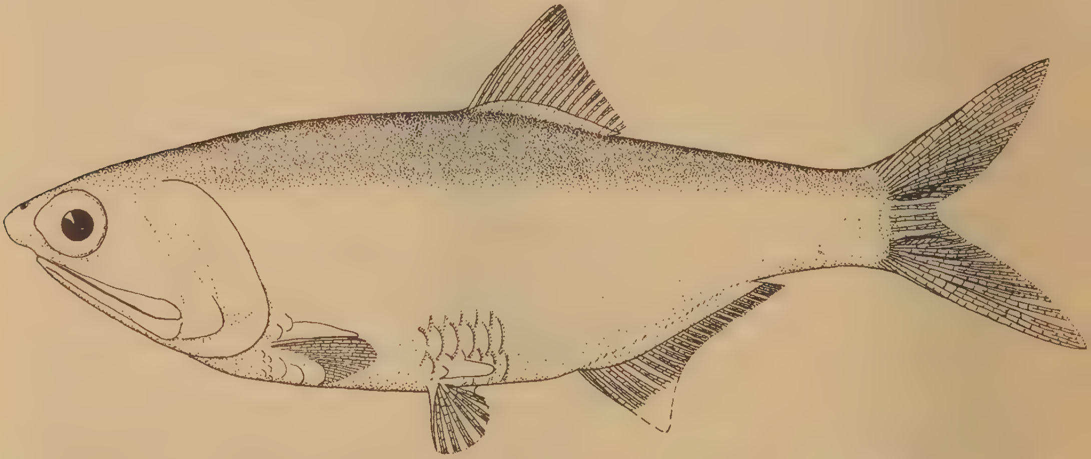

Figure 59. *Cetengraulis edentulus*, 120 mm TL, 100 mm SL, from Havana, Cuba, USNM 35159. Drawn by Louella E. Cable.

Dorsal fin with the longest rays failing to reach tip of last ray if deflexed, its origin generally about equidistant between anterior margin of eye and caudal base. Anal with origin usually under last fourth of dorsal base, its base 4.3–4.6 in SL. Pelvic inserted nearer to anal origin than to pectoral base, generally reaching fully halfway to origin of anal. Pectoral usually failing to reach base of pelvic, 1.9–2.3 in head. Axillary scale of pectoral broad, with a somewhat thickened ventral edge, 3.25–3.7 in head.

Color. In alcohol, bluish gray above; lower 75% of side silvery. Small specimens with a silvery lateral band, becoming wider and less distinct with age, generally disappearing at a length of about 100 mm.

Size. Specimens as much as 165 mm (6.6 in.) TL have been reported.

Range and Habitat. Reported for the West Indies and the Atlantic coast of Panama to southern Brazil. It ascends freshwater streams.

Synonyms and References:

Engraulis edentulus Cuvier, Règne Anim., ed. 2, *2*, 1829: 323 (orig. descr.; type local. Jamaica); Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 51 (descr., abund., distr.).

Cetengraulis edentulus Günther, Cat. Fish. Brit. Mus., *7*, 1868: 383 (descr., range); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 450 (descr., range, synon.); Meek and Hildebrand, Field Mus.

Publ., Zool., *15* (1), 1923: 214 (descr., range; *Stolephorus garmani* Evermann and Marsh and *S. gilberti* Evermann and Marsh put in synon.); Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67*, 1926: 414 (descr., Cuba and Brazil); Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 49, fig. (descr., Port-au-Prince, Haiti); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 206, fig. (synon., diagn., Puerto Rico); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 51 (range, synon.); Fowler, Proc. Acad. nat. Sci. Philad., *80*, 1931: 393 (Trinidad, B.W.I.); Beebe and Hollister, Zoologica, N. Y., *19* (6), 1935: 211 (Union I., B.W.I.); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 135 (Brazilian recs.); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 155, fig. 71 (descr., synon., range); Schultz, Proc. U. S. nat. Mus., *99*, 1949: 54 (refs.).

Engraulis brevis Poey, Repert. Fisico-Nat. Cuba, *1*, 1866: 379 (orig. descr.; type local. Cuba; cf. *E. edentulus* Cuvier); Howell-Rivero, Bull. Mus. comp. Zool. Harv., *82*, 1838: 172 (holotype, MCZ 24296, Poey's No. 716).

Stolephorus robertsi Jordan and Rutter, Proc. Acad. nat. Sci. Philad., *49*, 1897: 95 (orig. descr.; type local. Jamaica; type SU 4853; cf. *Stolephorus opercularis* Jordan and Gilbert, a Pacific coast *Cetengraulis*); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (3), 1898: 2815 (descr. after Jordan and Rutter).

Stolephorus gilberti Evermann and Marsh, Rep. U. S. Comm. Fish. (1899), 1900: 352 (orig. descr.; type local. Palo Seco, Puerto Rico; type USNM 49359; cf. *Engraulis productus* Poey = *Engraulis clupeoides* Swainson and *Stolephorus garmani* E. and M. = *Engraulis edentulus* Cuvier); and Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 90, fig. 15 (orig. descr.); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (4), 1900: 3146 (descr. after Evermann and Marsh).

Stolephorus garmani Evermann and Marsh, Rep. U. S. Comm. Fish. (1899), 1900: 352 (orig. descr.; type local. Puerto Real, Puerto Rico; type USNM 49360; cf. *Engraulis productus* Poey = *Engraulis clupeoides* Swainson, and *Stolephorus gilberti* E. and M. = *Engraulis edentulus* Cuvier); and Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 89, fig. 14 (orig. descr.); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (4), 1900: 3146 (descr. after Evermann and Marsh).

Anchoviella robertsi Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 49 (range, synon.).

Cetengraulis gilberti Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 51 (range, synon.); Howell-Rivero, Proc. Boston Soc. nat. Hist., *41* (4), 1936: 55 (Cuba).

Cetengraulis garmani Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 51 (range, synon.).

Doubtful References:

Stolephorus surinamensis Bleeker, Tijd. Dierk. Amst. (1865) *3*, 1866: 178 (orig. descr. of 96-mm specimen; type local. Surinam; nothing in descr. inconsistent with *C. edentulus* of similar size); Eigenmann, Mem. Carneg. Mus., *5*, 1912: 448 (descr. of 27- and 37-mm specimens from Bartica Rocks, British Guiana); Puyo, Bull. Soc. Hist. nat. Toulouse, *80*, 1945: 103, fig. 2 (descr., French Guiana); Puyo, Faune Emp. Franç., 12, Poiss. Guyane Franç., 1949: 155, fig. 78 (descr., French Guiana).

Stolephorus manjuba Miranda-Ribeiro, Kosmos, Rio de J., Feb., 1908, 5—no pagination (orig. descr. inadequate; type local., Rio de Janeiro, Brazil).

Anchovia gilberti Fowler, Proc. Acad. nat. Sci. Philad., 1916: 401 (Colón, Panama, without comment).

Anchoviella surinamensis Fowler, Proc. Acad. nat. Sci. Philad., *80*, 1931: 392 (three specimens, 34–36 mm long, from Icacos Beach, Trinidad, B.W.I.; notes suggest *C. edentulus*).

Cetengraulis juruensis Boulenger 1898

Study Material. None.

Distinctive Characters. See Key to Atlantic Species, p. 245.

Description. Based on original description and figure, which is all that is known. BODY depth 20% of SL. HEAD 28.5 in SL. SNOUT projecting strongly (extending nearly its full length beyond mandible, according to a published figure). EYE 5.5 in head. MAXILLARY extending to joint of mandible. GILL RAKERS long, finely denticulate, about 40 on lower limb.

DORSAL origin equidistant between tip of snout and caudal base; 13 rays. ANAL origin under posterior rays of dorsal; rays 23. PELVIC fin inserted somewhat nearer to base of pectoral than to origin of anal. PECTORAL extending a little beyond base of pelvic, its length a little more than half of length of head. AXILLARY SCALE of pectoral extending somewhat beyond midlength of fin (according to figure). SCALES 38.

Color. Olive above, silvery on sides and below. Snout blackish above. Fins pale orange; caudal rays blackish at tips.

Range and Habitat. Known only from the holotype, a specimen 140 mm TL, from fresh water, from the Juruá River, a tributary of the Amazon in Brazil.

References:

Cetengraulis juruensis Boulenger, Trans. zool. Soc. London, *14* (10), 1898: 427, pl. 41, fig. 3 (orig. descr.; type local. Rio Juruá, Brazil; cf. *C. edentulus*); Eigenmann, Rep. Princeton Exped. Patagonia, 1896–1899, *3* (4), 1910: 452 (refs. to orig. descr., habitat); Campos, Arqu. Zool. estad. São Paulo, *3* (7), 1941: 202, fig. 15 (descr., range); Hildebrand, Bull. Bingham oceanogr. Coll., *8* (2), 1943: 158 (descr. after Boulenger).

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Printed in Denmark for the Sears Foundation for Marine Research. Yale University, New Haven, Connecticut, USA.
Bianco Lunos Bogtrykkeri AS, Copenhagen, Denmark

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Family Clupeidae[1]

SAMUEL F. HILDEBRAND[2]

excepting

Genus *Harengula* by Luis R. Rivas
Genus *Dorosoma* by Robert R. Miller

Characters. Body usually slender in most but short and deep in a few species; slightly to excessively compressed in most but almost round in some. Scales covering body; cycloid, serrate, or pectinate; head naked. Chest and abdomen compressed into a sharp edge, armed with Bony scutes, except in the Dussumierinae (see 1 a in Key to Genera). Lateral line wanting. Mouth moderately large, terminal, superior or inferior. Teeth in jaws small, or canine-like in Chirocentrinae (see 11 b in Key to Genera), sometimes wanting in large adults of *Alosa*. Gill rakers usually long, slender, numerous, increasing in number with age and growth in some species, in moderate numbers in others. Gill membranes not united, free from the isthmus. Pseudobranchiae present. Dorsal fin, if present, usually about at midlength of the standard length, but sometimes posterior (present in American species). Adipose fin absent. Caudal fin forked. Anal moderately long to very long. Pelvic fin moderately large, small, or absent. Pectoral fin well developed. Vertebrae in species of the western North Atlantic about 39–59.

Remarks. This large family, composed of about 70 genera and perhaps 150 or more species, of which 16 genera and 36 species come within the scope of this work, is economically one of the most important groups of fishes in the world. Many of the species occur in great schools, making it easy for either man or natural predators to

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[1] Edited, with some revision and expansion, by George S. Myers, Henry B. Bigelow, Mywanwy M. Dick, and Yngve H. Olsen.
Some of the subfamilies recognized herein, particularly the Dussumierinae and Dorosomatinae, have been treated as separate families in some recent works. Nevertheless their affinities are with the Clupeidae. For practical purposes, therefore, the characters of the subfamilies have been sufficiently indicated in the Key to Genera (p. 259) for the major subdivisions to be recognized without further treatment elsewhere.

[2] August 15, 1883 – March 16, 1949.

Reprinted from Memoir Sears Foundation for Marine Research, I (3), 1963: 257–454

catch them in large quantities; and the supply of some, such as those of the genus *Clupea*, seems to be almost inexhaustible. Fresh herring are used extensively as food by man in nearly all parts of the world, and in many areas large quantities are eaten after they have been salted and smoked or canned. Great quantities, especially of *Brevoortia*, are reduced to oil, fish meal (feed for livestock and poultry), and fertilizer. The smaller species and the young of the larger ones serve still another useful purpose in providing extensive forage for larger predatory fishes, many of which enter into the diet of man. Aquatic mammals, birds, and turtles also feed on them. All this food is provided for man and beast at virtually no cost, as the herring feed almost entirely on small organisms that are not suitable food for man or for the other predators named.

Although the members of the family Clupeidae have no lateral line, nearly all of the species described in this work have numerous mucous pores and canals about the head and shoulders that may in part compensate for the absence of a lateral line. An air bladder with a very thin wall is present in all the species of the genera examined, namely *Clupea*, *Alosa*, *Pomolobus*, *Brevoortia*, *Opisthonema*, *Harengula*, *Sardinella*, and *Etrumeus*, and it may be assumed that the other members of the family also have an air bladder. Its walls are so thin and delicate that dissections must be made with care to find it undamaged.

Range. Herring (Clupeidae) occur in all seas of the world except those of the Arctic and Antarctic regions. Many species ascend freshwater streams to spawn, and others live in fresh water permanently.

Preparation of Descriptions and Location of Study Material. Nearly all *Descriptions* were prepared directly from specimens, but a few are included for which no specimens were available. In such instances it is stated in the accounts that they were compiled or quoted from publications. The specimens used are in the USNM unless otherwise stated. Freshwater species occurring in the rivers draining into the western North Atlantic are not numerous and have been included for the sake of completeness; it is possible that all of these forms occasionally enter brackish or salt water.

Measurements and Counts. The proportions used in *Description* are based on measurements made with vernier calipers having sharp straight points. Many of the measurements of small fish (sometimes even of larger ones) and of the small structures such as eye, snout, and maxillary were made under magnification. See also Measurements and Counts under *Brevoortia*, p. 343.

Total length: distance between margin of snout or tip of lower jaw (whichever is longer), more or less along the body axis to a vertical at tip of longest lobe of caudal fin.

Standard length: distance between anterior margin of snout and base of caudal.

Body depth: greatest depth unless otherwise stated; this may occur over base of pectoral or as far back as origin of dorsal fin.

Head: if used without a modifier, the distance between anterior margin of snout and most distal point of bony (not membranous) margin of opercle.

Head depth: distance from a slight crossgroove at the occiput, between the naked head and scaly body, to margin of first ventral scute; this line may be vertical or may slope somewhat backward from the occipital crossgroove.

Snout: distance from anterior margin of snout to anterior margin of orbit.

Eye: horizontal diameter of eyeball, not of orbit.

Maxillary: distance from anterior rim of snout to maxillary's posterior margin.

Mandible: distance from its tip to its joint.

Interorbital: width of bone over or between middle of eyes.

Cheek: the bone, usually with a glossy surface in the herrings, lying below and usually somewhat behind the eye, its depth measured from lower rim of orbit to its lowest or deepest point.

Predorsal length: distance between anterior margin of snout and origin of dorsal.

Caudal lobes: distance from midbase of this fin to tip of lobe.

Pelvic and Pectoral fins: distance from base of outer or upper ray to tip of fin.

Fin ray count: includes all rays, whether rudimentary, simple, or branched; the last ray, even though nearly double, counted as one.

Scales: range in scale numbers, e.g. 56–62, obtained by counting the oblique rows (upward and slightly forward) that cross the side between upper anterior angle of gill opening and base of caudal; any deviation from that procedure is stated.

Gill rakers: number present on first gill arch, including rudiments if present; all enumerations based on adult fish unless stated otherwise.

Ventral scutes: three sets of counts are given: the range of the total number present, the number in front of the pelvic fins, and the number behind these fins; the scute ending nearest to the insertion of the pelvics is included in the number in advance of these fins; the rest compose the number behind.

Vertebrae: total number, including the hypural.

Key to Western North Atlantic Subfamilies and Genera of Clupeidae[3]

1a. Body little compressed; abdomen rounded, covered with ordinary scales, without bony scutes. Subfamily Dussumierinae.

Atlantic coast of North America; eastern and western Pacific; southeastern coasts of Africa and Australia.

- 2a. Pelvic fin much smaller than pectoral, inserted behind base of dorsal; dorsal fin with about 17–20 rays; chest round. *Etrumeus* Bleeker 1853, p. 262.
- 2b. Pelvic fin nearly as large as pectoral, inserted under base of dorsal; dorsal fin with only about 9–14 rays; chest slightly keeled. *Jenkinsia* Jordan and Evermann 1896, p. 267.

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[3] This Key is drawn up simply for the ready identification of representatives of the subfamilies and genera that are known from the western North Atlantic without reference to those outside of this range. Therefore, some characters are used that apply only to the representatives described in this work and for that reason are not of generic value.

1b. Body moderately to very strongly compressed; chest and abdomen compressed into a sharp keel armed with bony scutes.

3a. Median line of back in front of dorsal fin with ordinary or modified scales, thus without a prominent median naked strip; stomach not gizzard-like, but wall somewhat thickened in some species.

4a. Pelvic fin well developed, inserted under base of dorsal, with 7–9 rays; mouth gently oblique, the lower jaw usually included but occasionally projecting; body moderately compressed. Subfamily Clupeinae.

Virtually all temperate and tropical waters of the world, with some species entering frigid zones; inhabiting salt, brackish, and fresh water.

5a. Vertical edge on rim of shoulder girdle (cleithrum) underneath free edge of gill cover (opercle) smooth or even, without dermal lobes.

6a. Back in front of dorsal fin with ordinary scales like those on rest of body; pelvic with 8 or 9 rays; pectoral fin without a free axillary process; scales not overlapping deeply, their exposed part not much deeper than long, their margin slightly irregular, not definitely serrate or pectinate.

7a. Vomer with teeth; greatest depth of body about 4.0–5.0 in SL; ventral scutes weak, numerous, total number about 39–46. *Clupea* Linnaeus 1758, p. 274.

7b. Vomer toothless; depth of body generally less than 4.0 in SL; ventral scutes strong, total number about 27–38.

8a. Upper margin of lower jaw within mouth rising gently; teeth missing in examples 200 mm and upward in length; cheek deeper than long (Fig. 69). *Alosa* Link 1790, p. 293.

8b. Upper margin of lower jaw within mouth rising abruptly; teeth present, at least in lower jaw, at all ages; cheek not deeper than long, definitely longer than deep in some species (Fig. 76). *Pomolobus* Rafinesque 1820, p. 312.

6b. Back in front of dorsal fin with a row of enlarged modified scales on each side of median line; pelvic with 7 rays; pectoral fin with a free axillary process; scales overlapping deeply, their exposed part much deeper than long, their margin strongly serrate to pectinate (Fig. 85). *Brevoortia* Gill 1861, p. 342.

5b. Vertical edge on rim of shoulder girdle (cleithrum) underneath free edge of gill cover (opercle) with two dermal lobes (Fig. 100).

9a. Last ray of dorsal greatly produced, filamentous, often reaching nearly or quite to base of caudal (Fig. 94); anal with 20–25 rays. *Opisthonema* Gill 1861, p. 380.

9b. Last ray of dorsal little if any longer than the preceding ones; anal with about 15–20 rays.

10a. Last two rays of anal not enlarged; gill rakers about 25–40 on lower limb; scales about 34–41 oblique series crossing middle of side; pelvic with 8 rays.
Harengula Cuvier and Valenciennes 1847, p. 386.

10b. Last two rays of anal enlarged, finlet-like (Fig. 100); gill rakers about 70–130 on lower limb; scales about 41–47 oblique series crossing middle of side; pelvics with 9 rays.
Sardinella Cuvier and Valenciennes 1847, p. 397.

4b. Pelvic fin small or wanting, inserted in advance of dorsal fin if present; mouth strongly oblique to nearly vertical, the lower jaw projecting; body strongly to excessively compressed.

11a. Teeth in jaws all small, without canines; vomer toothless.
Subfamily Pristigasterinae.

12a. Maxillary with a short sharp spine near anterior end, just behind premaxillary (Fig. 103); anal fin small, beginning far behind base of dorsal, with only about 15–18 rays.
Rhinosardinia Eigenmann 1912, p. 411.

12b. Maxillary without a spine; anal fin much longer, beginning in front of dorsal fin, under it, or immediately behind it, with more than 30 rays.

13a. Pelvic fin present; dorsal fin moderately large, with about 15–20 rays. *Ilisha* Gray 1846, p. 415.

13b. Pelvic fin wanting; dorsal fin with about 10–15 rays.

14a. Body with chest and abdomen greatly dilated, more or less half-moon shaped (Fig. 108), its greatest depth about half of its SL; median line of back in front of dorsal fin with several short spines.
Pristigaster Cuvier 1817, p. 427.

14b. Body elongate, with chest and abdomen not greatly dilated, its greatest depth less than a third of its SL; no external spines on median line of back.

15a. Body excessively compressed; dorsal outline more or less concave over the head; a toothless membranous section between maxillary and premaxillary, the three elements forming a continuous margin; maxillary greatly produced in large adults (Fig. 111); anal fin with about 52–80 rays.
Odontognathus Lacépède 1800, p. 430.

15b. Body rather strongly but not excessively

compressed; dorsal outline convex over head; maxillary and premaxillary not separated by a membranous section; maxillary overlapping distal end of premaxillary, interrupting margin of upper jaw (Fig. 113); anal fin with only about 39–48 rays.
Neoopisthopterus Hildebrand 1948, p. 435.

11b. Teeth in jaws of unequal size, both jaws with strong canines (Fig. 115); vomer with teeth. Subfamily Chirocentrinae.
Chirocentrodon Günther 1868, p. 438.

3b. Median line of back in front of dorsal fin naked, not crossed by scales; stomach with very thick walls, like the gizzard of a fowl. Subfamily Dorosomatinae.
Dorosoma Rafinesque 1820, p. 443.

Genus *Etrumeus* Bleeker 1853

Round Herrings

Etrumeus Bleeker, Verh. Batav. Genoot., *25*, 1853: 48; genotype by monoytpy, *Clupea micropus* Temminck and Schlegel.

Generic Synonym:

Perkinsia Rosa Eigenmann, Amer. Nat., *25*, 1891: 153; type species by monotypy, *P. othonops* Rosa Eigenmann equals *Clupea micropus* Temminck and Schlegel.

Characters. BODY elongate, little compressed, especially in Atlantic species; chest and abdomen fully rounded. BONY SCUTES absent. SCALES with smooth edges, deciduous, covering chest and abdomen. SNOUT long, tapering. MOUTH terminal. MAXILLARY slender, ending about under anterior margin of eye. TEETH minute, present on jaws, vomer, palatines, pterygoids, and tongue. DORSAL fin beginning notably nearer to margin of snout than to base of caudal, with about 17–20 rays. ANAL about half as far from base of caudal as from origin of dorsal, with about 10–12 rays. PELVIC fins inserted well behind base of dorsal, with a shield of enlarged scales covering them in part, each fin with 8 rays. PECTORALS of moderate size, also shielded in part by enlarged scales, each fin with about 14–16 rays. Pelvic and pectoral each with a long AXILLARY PROCESS.

Range. Represented by one species on the Atlantic and Gulf coasts of the United States, and by two or more species in the eastern and western Pacific on the coasts of southeastern Africa and southeastern Australia.

Etrumeus sadina Mitchill 1814

Atlantic Round Herring

Figures 62, 63

Study Material. Many specimens, postlarvae to adults, 25–180 mm TL, the specimens from New Jersey northward being adults caught near or on the shore, those from off Cape Lookout, northern Florida, and the Gulf of Mexico, mostly young, taken quite a distance offshore in 5–21 fms. depth except for a lot of six small ones from Beaufort Inlet, North Carolina, taken in water only about 2–3 fms. deep.

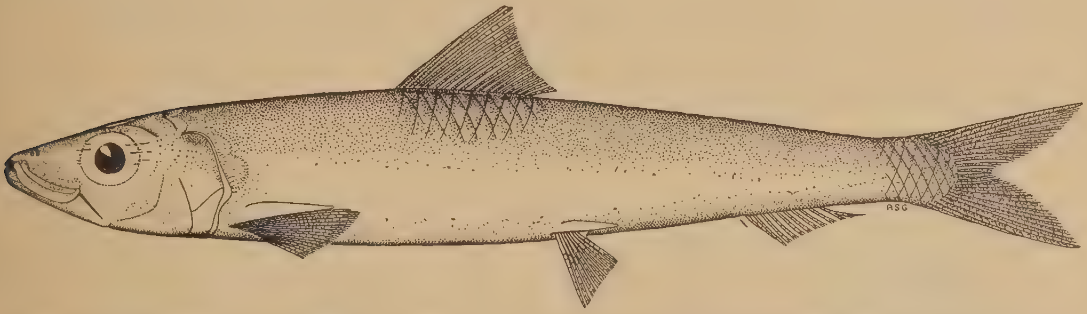

FIGURE 62. *Etrumeus sadina*, female, 140 mm TL, 115 mm SL, Woods Hole, Massachusetts, USNM 143574. Drawn by Ann S. Green.

Distinctive Characters. The very slender and roundish body, the roundish chest and abdomen covered with ordinary scales, the absence of bony scutes, the small anal fin situated near the base of the caudal, and the rather small pelvic fin inserted entirely behind a vertical from the base of the last dorsal ray, readily distinguish this species from other American clupeoids.

Description. Proportional dimensions in per cent of standard length, and counts, based on 22 specimens from *Study Material*, 55 mm (young adults)–180 mm TL, 45–154 mm SL.

Body: depth 16–18.5.
Caudal peduncle: depth 6.7–8.2.
Head: length 24–29.
Snout: length 6.0–9.5.
Eye: diameter 6.5–8.0.
Interorbital: width 3.0–4.4.
Maxillary: length 7.0–10.5.
Anal fin: length of base 5.6–6.9.
Pelvic fin: length 8.9–11.5.
Pectoral fin: length 14–17.

Distance from snout to origin of: dorsal 42–46.

Scales: about 48–55, usually lost in preserved specimens.
Gill rakers: 32–38 on lower limb, *ca.* 14 on upper limb.
Fin rays: dorsal 16–20, usually 18 or 19; anal 10–12, most frequently 11; pectoral 14–16.
Vertebrae: 49 (7 specimens).

Body almost round, its greatest thickness about 80% of its depth, its greatest depth 5.4–6.25 in SL; ventral profile a little more strongly convex than dorsal profile. Caudal peduncle compressed, its depth 3.3–3.9 in head.

Scales deciduous, usually lost in preserved specimens, very thin, scarcely deeper than long, with even edges.

Head low, rather long, 3.45–4.15 in SL. Snout equal to or more usually longer than eye, tapering, 3.0–3.9 in head. Eye with much adipose tissue in adults, 3.25–4.1 in head. Interorbital bone 6.25–7.55. Maxillary obliquely rounded posteriorly, reaching about under anterior margin of eye, 2.6–3.0 in head. Mandible coterminal with snout, 1.85–2.0 in head. Gill rakers rather slender, moderately close-set, those at angle somewhat exceeding half of length of eye; apparently not increasing in number with age. Teeth small, in a single series on mandible; a few minute teeth on premaxillaries, and a row on the margin of maxillaries; very small granular teeth on vomer, palatines, pterygoids, and tongue.[4]

Dorsal fin moderately elevated anteriorly, with concave margin, its longest rays generally not reaching tip of posterior ray if deflexed, its origin about equidistant between margin of snout and vertical from middle of anal base, its distance from snout 2.15–2.4 in SL. Caudal fin forked, the lobes of about equal length, generally somewhat longer than head without snout. Anal small, rather feebly developed, placed far behind dorsal fin, a little nearer to base of caudal than to base of pelvic, its base 3.5–4.5 in head. Pelvic fin rather short and broad, with nearly straight margin, inserted a little behind vertical from base of last ray of dorsal, generally a little nearer to base of pectoral than to base of caudal, 2.3–3.0 in head; a membranous axillary process present, about 67% of the length of fin. Pectoral fin moderately developed, reaching notably less than halfway to base of pelvic, inserted fully an eye's diameter nearer to tip of mandible than to base of pelvic, 1.5–1.8 in head; a long membranous axillary process present about 0.83 of length of fin.

Alimentary canal about half of SL. Stomach with a long blind sac and numerous pyloric caeca. Air bladder long and narrow.

Color. Fresh specimens olive green above, silvery on lower half of side and below. In old preserved specimens, back generally brownish and lower parts pale (sometimes silvery).

Size. A length of 200–250 mm (8–10 in.) is said to be attained by this species.

Development. The postlarvae and young adults are very slender, as is usual in young herrings. In postlarvae 25–28 mm TL (21–24 mm SL) the body depth is contained about 16–24 times in the SL; the jaws are weakly developed; the teeth are not evident; the snout is proportionately longer than that in adults, being 1.5–2.0 times longer than the eye; the pectoral fins are not much more than tufts of membrane; and the pelvics are incompletely developed. The larval pigment spots are still retained, chiefly in a single slightly broken dark line on the chest, in two diverging dark lines on the abdomen, in a row of dark spots along each side of the base of

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[4] To see the teeth clearly it may be necessary to dry the head.

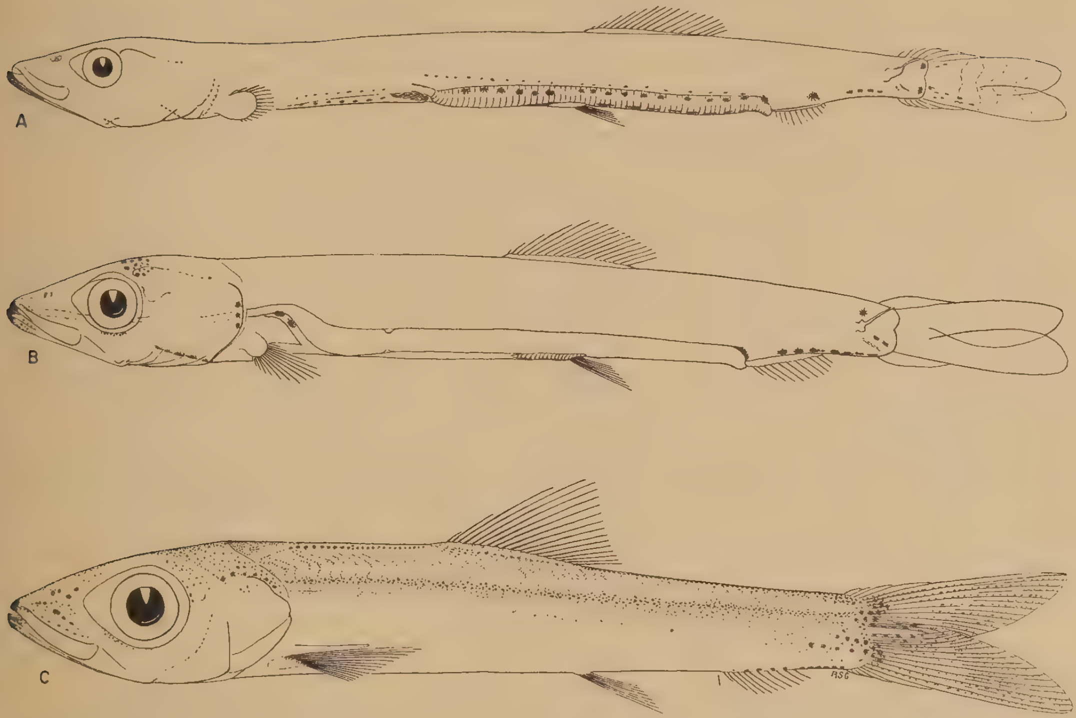

FIGURE 63. *Etrumeus sadina.* A, larva, 27.5 mm TL, near Pensacola, Florida. B, young, 35 mm TL, near Pensacola, Florida. C, young, 42.5 mm TL, Beaufort, North Carolina, USNM 143804. All drawn by Ann S. Green; A and B based on camera-lucida sketches by W. W. Welsh.

anal, and in a single dark median line behind the anal fin; also several dark spots are present on the base of the caudal.

At about 33–35 mm TL, the fins are all rather fully developed and the body has become proportionately much deeper, but the pigmentation remains virtually the same as in smaller examples. Specimens of this size, then, may be classed as young adults. General pigmentation is delayed and is scarcely complete at 55 mm TL. The fish continue to increase in relative depth as long as they grow.

Spawning. The smallest specimens at hand, postlarvae 25–28 mm TL, are so young that they probably were caught not far from where they were hatched; they were taken at 30°29′ N, 80°37.5′ W, off northern Florida. Still smaller larvae, 7.6–21 mm, were listed by the late W. W. Welsh in his unpublished notes, accompanied by seven camera-lucida sketches. These were taken by the GRAMPUS at the surface in the Gulf of Mexico at 28°21′ N, 89°06′ W, 17 miles or so off the Mississippi Delta. Although these specimens are apparently no longer extant, the drawings leave no room for doubt as to their identity. Also in this as well as other collections there are young adults from northern Florida south to Cape Canaveral and from the Gulf of Mexico off Mobile Bay. The smallest young (including postlarvae) were taken on January 25 (1940), and other small young adults were taken in March off northern Florida and in the Gulf of Mexico. The smallest young were caught in water 19 fms. deep, and other small ones were taken at 21, 20, 16, and 5 fms. From these data it may be concluded that spawning in the south takes place during the winter, somewhat offshore, and in water several fathoms deep. If spawning takes place northward it seems not to have been reported.

Migration and Habitat. In the northern part of its range, as at Woods Hole, Massachusetts, this Round Herring is taken along the shore only during summer. It has not yet been determined whether this fish migrates northward during summer or whether it only comes inshore from deep water during warm weather. In southern waters it is not known to occur along the shore, for there it has been taken only offshore in water a few to several fathoms in depth. Whether it migrates at all in these waters remains unknown.

Relationships. E. sadina is the only representative of the genus in the Atlantic, but other species occur in the Pacific: off California, the Philippine Islands, Japan, Hawaii, and Galapagos Islands. Those from the western Pacific are more compressed and proportionately deeper than the Atlantic species and are therefore less typically "round herrings."

Abundance. Generally this Round Herring is rare to scarce from New Jersey to New England, where it occurs along the shore, but occasionally it is common to plentiful. It was very abundant off Woods Hole, Massachusetts, in 1905 and again in 1908 (*123*: 741). A number of specimens was also taken at Campobello Island at the mouth of the Bay in September 1937 (*82*: 5; *92*: 15). Along the coast of eastern Maine, in August-September 1953, something like 200,000 pounds were landed (*114*: 194). But apparently it has been taken only sparingly off the southern Atlantic and Gulf coast states, though commonly regarded as a warm-water fish.

Range. It is known from Passamaquoddy Bay at the mouth of the Bay of Fundy and from the eastern part of Maine to northern Florida off Cape Canaveral, and from the Gulf of Mexico.[5] Although it has been reported as not rare southward (*72*, 1896: 420), no records have been found of its occurrence from Delaware southward; and there is only one record for the Gulf, the latter being based on specimens taken from the stomachs of snappers landed at Pensacola, Florida (*74*: 143). Recent collections by the U.S. Fish and Wildlife Service include: examples from Beaufort Inlet and off Cape Lookout, North Carolina; four collections of young from off northern Florida southward to Cape Canaveral; and six collections from the Gulf of Mexico, five of these from off Mobile Bay and one from south of New Orleans. These rather recent collections are all from offshore waters of 2–21 fms. depth. Those from New Jersey northward, all adults, were caught in shallow water near or on the shore.

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5. Bertin (*13*:9) synonymized *E. microps* and *E. jacksoniensis*, previously recognized as valid species, and thereupon gave the range as the Atlantic coast of the United States, the coast of southeastern Australia, southeastern Japan, Hawaii, and the southeastern coast of Africa. However, from comparison of specimens from the United States and Japan, it was at once evident that the latter were different in shape, being especially more compressed. A further study of specimens from the widely separated regions where the genus occurs would be desirable.

Apparently this fish does not occur off southern Florida, for it was not reported by Longley and Hildebrand from collections made at Tortugas over many years, including dredgings at various depths down to about 400 fms (*87*). This seems to be another instance of a discontinuous range of the genus such as is reported for *Pomolobus*, *Alosa*, and *Brevoortia* (p. 343). However, in *Etrumeus* the inhabitants of the Gulf and the Atlantic appear to be identical, whereas in the other genera named, the inhabitants of the two areas differ sufficiently to be recognized as distinct species.

Synonyms and References:

Clupea sadina Mitchill, Rep. in part on Fishes of New York, 1814: 21 (orig. descr.; type local. presumably New York; type lost); Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 457 (descr., New York[6]).

Alosa teres DeKay, N. Y. Fauna, Fishes, Pt. 4, 1842: 262, pl. 40, fig. 128 (orig. descr.; type local. New York Harbor; type in State Coll.).

Etrumeus teres Günther, Cat. Fish. Brit. Mus., 7, 1868: 467 (synon., notes, range); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1883: 263 (diagn., refs.); Jordan and Gilbert, Proc. U. S. nat. Mus. (1883), *6*, 1884: 143 (from stomachs of snappers, Pensacola, Florida); Bean, T. H., Bull. U. S. Fish Comm. (1887), *7*, 1888: 148 (Great Egg Harbor Bay, New Jersey); Bean, T. H., Bull. N. Y. St. Mus., *60*, Zool. 9, 1903: 189 (synon., descr., New York); Fowler, Rep. N. J. St. Mus. (1905), 2, 1906: 93 (diagn., synon.); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7* (8), 1908: 36 (refs., New England); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31* (2), 1913: 741 (refs., parasites, Woods Hole, Massachusetts); Fowler, Proc. biol. Soc. Wash., *33*, 1920: 147 (New Jersey); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40* (1), 1925: 91, fig. 39 (descr., range, Gulf of Maine); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 63, fig. (diagn., distr.).

Etrumeus sadina Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 420 (descr., range, synon.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 46 (synon., range); Bigelow and Schroeder, Bull. U. S. Bur. Fish., *48* (20), 1936: 327 (Yarmouth R. and Casco Bay, Maine); Bertin, Bull. Inst. océanogr. Monaco, 853, 1943: 9, fig. 4 (synon., descr., distr., etc.); Bigelow and Schroeder, Fish. Bull. (74) U. S. Fish Wildl. Serv., *53*, 1953: 87 (Gulf of Maine).

Genus *Jenkinsia* Jordan and Evermann 1896

Dwarf Herrings

Jenkinsia Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 418; genotype by monotypy, *Dussumieria stolifera* Jordan and Gilbert equals *Clupea lamprotaenia* Gosse.

Characters.[7] A very small species. BODY slender, compressed; abdomen rounded; chest with suggestion of a keel. BONY SCUTES absent. SCALES deciduous, very thin, with smooth edges, covering abdomen. SNOUT moderately long, tapering. MOUTH terminal. MAXILLARY narrowly rounded, terminating about under anterior margin of pupil. TEETH in a single series on the margin of maxillary and premaxillary; a short toothless membranous section present between these elements; no teeth on mandible or vomer; at most a few granular teeth on palatines, pterygoids, and tongue. DORSAL small, beginning rather nearer to margin of snout than to base of caudal, with about 9–14 rays. ANAL only a little larger than dorsal and placed far behind it, with about 12–16 rays. PELVIC fins nearly as long as the pectorals, each with 8 rays; a scale process present between fins at base. PECTORAL fins rather small, each with about 10–14 rays. Pelvic and pectoral both without a free AXILLARY PROCESS.

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[6] Because of such inaccurate statements in the original description as "Mouth . . . toothless," "Lower jaw projecting," and "A. 15," it was long questioned whether *sadina* was available for this species. However, the description contains pertinent remarks such as "Form neat, tapering, and slender," and especially "the belly is not at all serrate, but quite smooth," which can scarcely apply to any other clupeoid. Therefore, *sadina* certainly seems available. Apparently *Alosa teres* DeKay, though much better described and rather well figured, must rest in synonymy, under the rules of zoological nomenclature.

[7] Bertin (*13*: 17) has stated that *Jenkinsia* is not separable from *Spratelloides* Bleeker.—G. S. Myers.

Remarks. Jenkinsia resembles *Etrumeus* in having a rather roundish, elongated body, a rounded abdomen, and no bony scutes on the ventral outline of the chest and abdomen. However, in *Jenkinsia* the chest is very slightly keeled. The rather small anal fin, situated far behind the dorsal, and the rather large pelvic fin, inserted under the anterior half of the base of dorsal, also help to distinguish this genus. The small size of these herrings, about 50–70 mm, also separates them from other herrings.

Range. Known from Bermuda, doubtfully from North Carolina, the Florida Keys, the West Indies, and from some small islands in the Caribbean Sea, off México and Central America. Only two species are known.

Key to Species

1a. Gill rakers not especially close-set, 19–24 (usually 20 or 21) on lower limb; oblique series of scales crossing silvery lateral band between margin of opercle and base of caudal, 33–37. *lamprotaenia* (Gosse) 1851, below.

1b. Gill rakers close-set, 27–30 on lower limb; oblique series of scales crossing silvery lateral band between margin of opercle and base of caudal, 39–42. *viridis* (T. H. Bean) 1912, p. 272.

Jenkinsia lamprotaenia (Gosse) 1851

Dwarf Herring, Green Fry

Figure 64

Study Material. Many specimens, 28–65 mm TL, 23–55 mm SL, collected at Key West and Tortugas, Florida, the Bahama Islands, Cuba, Isle of Pines, Jamaica, Haiti, Puerto Rico, St. Eustatius Island, Old Providence Island, and Yucatán Island off Cozumel, México.

Distinctive Characters. See Remarks, and Key to Species, above.

Description. Proportional dimensions in per cent of standard length, and counts, based on 16 specimens, 40–65 mm TL, 32–55 mm SL.

Body: depth 15–20.
Caudal peduncle: depth 6.5–8.5.
Head: length 25–29.
Snout: length 6.2–8.0.
Eye: diameter 7.6–9.7.
Interorbital: width 3.8–5.4.

Maxillary: length 9.0–12.
Mandible: length 12–14.5.
Anal fin: length of base 10–14.
Pelvic fin: length 11–15.
Pectoral fin: length 14–17.
Distance from snout to origin of: dorsal 44–50.
Scales: 33–37, generally missing in preserved specimens.
Gill rakers: 19–24 (usually 20 or 21) on lower limb.
Fin rays: dorsal 9–13; anal 12–15; pectoral 10–13.
Vertebrae: 39 or 40 (6 specimens).

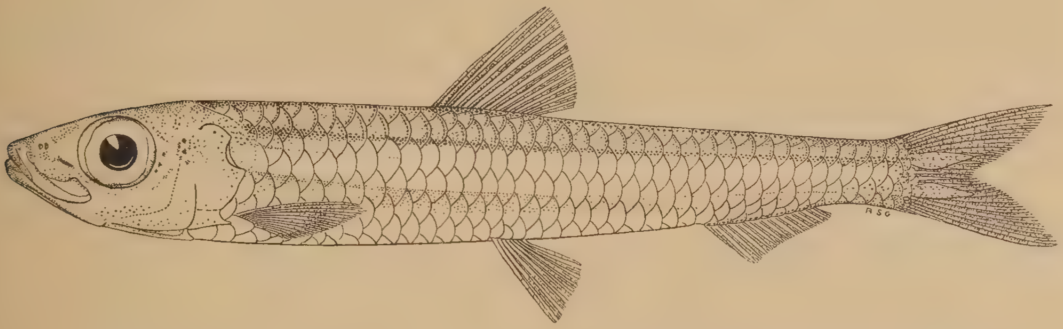

FIGURE 64. *Jenkinsia lamprotaenia*, 65 mm TL, 53 mm SL, Haiti, USNM 89600. Drawn by Ann S. Green.

BODY moderately compressed, its greatest thickness somewhat greater than half of its depth, its greatest depth 5.0–6.65 in SL; ventral outline more strongly convex than dorsal outline. CAUDAL PEDUNCLE rather strongly compressed, its depth 3.2–4.1 in head.

SCALES generally lost in preserved specimens, very thin, with smooth edges; those from middle of side below dorsal fin with a wavy ridge on anterior half, about 5 wavy radii behind it, and generally several shorter ridges at margin of scale.

HEAD rather low, 3.4–4.0 in SL. SNOUT generally shorter than eye, 3.4–4.2 in head. EYE 2.8–3.4. INTERORBITAL 5.5–7.0. MAXILLARY narrowly rounded posteriorly, reaching to or more usually a little beyond vertical from anterior margin of pupil, 2.25–2.75 in head. MANDIBLE generally included, not projecting, 1.9–2.2 in head. GILL RAKERS moderately close-set, those at angle of first arch about 75% of length of eye. TEETH missing on mandible and vomer but present in a single series on margin of premaxillary and maxillary, the series interrupted by a soft membranous section between these elements; palatines, pterygoids, and tongue at most with a few granular teeth.

DORSAL fin moderately elevated, the margin nearly straight, the longest rays reaching well beyond the tip of last ray if deflexed, the fin beginning notably nearer to margin of snout than to base of caudal, the distance from margin of snout 2.0–2.3 in SL. CAUDAL fin moderately forked, the lobes of about equal length, rather longer than head without snout; each lobe with a greatly elongated scale at base. ANAL fin much lower than dorsal, beginning far behind dorsal fin, about equidistant between insertion of pelvic and base of caudal, its base 1.9–2.6 in head. Pelvic fins only a little shorter than pectorals, with a large scaly process between them, the fins inserted under about 4th–6th dorsal ray, and generally close to an eye's diameter nearer to base of caudal than to tip of mandible; 1.9–2.5 in head. Pectoral fins somewhat pointed, inserted about equidistant between tip of mandible and base of pelvics, 1.6–1.9 in head.

Alimentary canal short. Stomach with a large blind sac. Pyloric coeca large, about 7. Peritoneum pale, with many dark dots.

Color. In life, faintly greenish above, with a distinct silvery lateral band. Preserved specimens straw colored, the silvery band persisting. Margin of mandible brown to black. Well-preserved specimens with an elongated silvery area on abdomen behind pectoral fin, and a similar though smaller area behind pelvic. Scales above lateral band with a brownish line on middle of exposed section, paralleling the curve of the margin of the scale; dark dots also present, especially in and above upper margin of silvery lateral band; two rows of dark dots on back; generally numerous dots on snout, including an elongated one in front of lower half of eye; an irregular dark spot at base of each anal ray, continued as a single median ventral line on caudal peduncle.

Size. The largest example at hand, 65 mm (2.6 in.) TL, may be near the maximum size attained.

Spawning and Development. Nothing is known definitely concerning reproduction in this species, but examples collected in 1937 at Kingston, Jamaica, during our winter months, contain well-developed eggs, indicating that at least some spawning takes place during that time around Jamaica.

The smallest examples at hand, a little more than an inch (28–30 mm) TL, are fully developed young adults. They differ principally from large examples from the same general locality (Tortugas, Florida) in being more slender, the depth being about 6.4 times in SL; in the large adult this proportion varies between about 2.25–5.6. However, there are large specimens in the collections studied that are just as slender as the young mentioned. For further discussion of the difference in depth, see *Variations* (p. 271).

Migration and Habitat. It seems improbable that this little fish travels long distances. It does occur in large compact schools that probably consist of millions of fish, as observed by me at Key West, Florida, and as reported for Tortugas, Florida (*49*: 156; *21*: 1). It moves about more or less like the young Atlantic menhaden, *Brevoortia tyrannus*, without pursuing any definite course.

Food. This species, like many other clupeoids, feeds on plankton, which it screens from the water as the school girates or mills around at the surface.

Enemies. Many large fish feed on this species. The gray snapper was mentioned especially by Gudger, who said that the little fish exhibited little fear; it hovered over the snapper in dense swarms but left a clear space around it approximately equal to the length of the snapper (*49*: 156). Whenever the snapper moved, the rather orderly school broke up but soon re-formed. Longley said, "Exceedingly common at Tortugas (Fla.), particularly along shore, where predacious fishes often drive them too close for safety, and large numbers are cast upon the windward beaches to spring about until a wave rescues them, or until they perish" (*87*: 12).

The copepod, *Colliparvus parvus* Wilson, was found on the gills of specimens taken at Nassau, Bahamas (*135*: 79), and an unidentified trematode was reported as parasitic on it at Tortugas, Florida (*90*: 372).

Relationships. Only two species of *Jenkinsia* are recognized herein. A third nominal species, *stolifera*, long was thought to be distinct, but recent works on taxonomy agree that it and *lamprotaenia* constitute one variable species; since *lamprotaenia* is the older name, *stolifera* has become a synonym. *J. viridis* is closely related to *lamprotaenia*, as shown in the account of *viridis* (p. 272).

Variations. This species, as indicated, is very variable. While the depth of body in general increases with age, adult specimens of equal size vary greatly in this respect among themselves, as is evident from the wide range shown in the *Description*. And this in turn is reflected in the wide range in the depth of the caudal peduncle and in the length of the head. A rather wide variation in the number of dorsal, anal, and pectoral rays, and in the number of gill rakers, is also shown in the *Description*. Although some of the earlier counts may have erred because fins are often broken in preserved specimens (no doubt so in the original description of *stolifera*), this error does not enter into those given in the foregoing *Description*, for ample specimens with undamaged fins were chosen for the enumerations.

Commercial Importance. Although this little Herring has been reported among the "white bait" in the market at Port-au-Prince, Haiti (*10*: 45), no doubt its chief value is that of providing food for foodfishes.

Range. Known from the Florida Keys, the Bahamas, throughout the West Indies, and from Swan Island, Glover Reef, and Cozumel Island in the Caribbean Sea; recently reported from Venezuela; doubtfully recorded for Beaufort, North Carolina. Apparently it is chiefly a shore species.

Synonyms and References:

Clupea lamprotaenia Gosse, Naturalist's Sojourn in Jamaica, 1851: 291, pl. 1, fig. 2 (orig. descr.; type local. Jamaica; types in BMNH; found in schools with an anchovy, *Engraulis brownii* = *Anchoa hepsetus*); Günther, Cat. Fish. Brit. Mus., 7, 1868: 465 (descr., Jamaica).

Dussumieria stolifera Jordan and Gilbert, Proc. U. S. nat. Mus. (1884), 7, 1885: 25 (orig. descr.; type local. Key West, Florida; type USNM 34964; local abund.); Bean, T. H., Bull. U. S. Fish. Comm. (1888), *8*, 1890: 206 (Cozumel, Yucatán).

Jenkinsia lamprotaenia Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 419 (descr., after Günther); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 84 (descr., refs., Puerto Rico); Metzelaar, Rapp. Vissch. Curaçao, ed. by J. Boeke, 1, W. Indian Fishes, 1919: 9, fig. (refs., descr., range; Leeward Is., West Indies); Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 43, fig. (refs., descr., range, *J. stolifera* synon.; Port-au-Prince, Haiti); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 63, fig. (diagn., range); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 201, fig. 32 (refs., distr., diagn., Puerto Rico); Parr, Bull. Bingham oceanogr. Coll., *3* (4), 1930: 3 (refs.; discus. ident. of *lamprotaenia* and *stolifera*; Bahamas, Turks Is.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 46 (range, refs.); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 12 (discus. *lamprotaenia* and *stolifera*; variability; Tortugas, Florida); Hildebrand, Copeia, 1941: 224 (extension of range, Beaufort, North Carolina); Fowler, Monogr. Acad. nat. Sci. Philad., 6, 1944: 123, fig. 30

(descr., locals., pp. 434, 456); Martin, Mem. Soc. Cient. La Salle, *15*, 1955: 184–188 (descr., ills., Venezuela).

Jenkinsia stolifera Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 419 (descr., ref. to orig. descr.); Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 55 (refs., Florida); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 84 (descr., refs., Puerto Rico); Bean, B. A. *in* Bahama Islands, Fishes, 1905: 297 (rec. from Spanish Wells); Fowler, Proc. Acad. nat. Sci. Philad., *58*, 1906: 81, fig. 1 (descr.; assoc. with anchovies; Florida Keys); Wilson, Proc. U. S. nat. Mus., *53*, 1917: 79 (host of copepod, *Colliparvus parvus* Wilson; Nassau, Bahamas); Breder, Bull. Bingham oceanogr. Coll., *1* (1), 1927: 13 (Isle of Pines, Swan I., and Glover Reef off British Honduras); Breder, Amer. Mus. Novit., 382, 1929: 1–5 (school. behav., Tortugas, Florida); Gudger, Publ. Carneg. Instn. Wash., 391, 1929: 156, pl. 1, fig. 6 (local abund., habits, Tortugas, Florida); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 46 (range, ref.); Breder, Publ. Carneg. Instn. Wash., 435, 1932: 8 (fed on by needlefish, *Strongylura*; Tortugas, Florida); Gowanloch, Bull. La. Conserv. Dep., 23, 1933: 214 (in great schools, Gulf of Mexico; but no records for Gulf coast north of extremes Florida, therefore, apparently not of Louisiana fauna).

Spratelloides lamprotaenia Bertin, Bull. Inst. océanogr. Monaco, 853, 1943: 17 (diagn., revision).

False References:

Jenkinsia stolifera Nichols (not of Jordan and Gilbert), Proc. biol. Soc. Wash., *33*, 1920: 63 (*Stolephorus viridis* in synon., Bermuda).

Jenkinsia lamprotaenia Beebe and Tee-Van (not of Gosse), Field Bk. Shore Fish. Bermuda, 1933: 37, fig. (field char., diagn., distr.); Beebe and Tee-Van, Zoologica, N. Y., *13* (7), 1933: 136 (refs., *Stolephorus viridis* and *J. stolifera* in synon., Bermuda); Hollister (not of Gosse), Zoologica, N. Y., *21* (4), 1936: 276, figs. 40–44 (caudal skel.).

Jenkinsia viridis (T. H. Bean) 1912

Bermuda Herring, Dwarf Herring, Green Fry

Figure 65

Study Material. A total of 19 specimens, 42–58 mm TL, 32–48 mm SL, as follows: 4 "types," from Bermuda, presumably from Hamilton, USNM 74084; the holotype, USNM 100546; and 14 paratypes of *Jenkinsia bermudana* Rivas, GRAMPUS St. 10178, off Bermuda, 32°20′ N, 64°21′ W.

Distinctive Characters. See *Relationships* (p. 273) and Key to Species (p. 268).

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 32–48 mm SL.

Body: depth 15–17.5.
Caudal peduncle: depth 6.7–8.2.
Head: length 25–27.
Snout: length 6.7–8.5.
Eye: diameter 7.0–9.0.
Interorbital: width 3.6–4.75.
Maxillary: length 9.4–10.8.
Mandible: length 11.6–13.5.
Anal fin: length of base 12–14.
Pelvic fin: length 12–15.
Pectoral fin: length 14–16.
Distance from snout to origin of: dorsal 44.5–50.

Scales: about 39–42, generally lost in preserved specimens.
Gill rakers: 27–30 on lower limb.
Fin rays: dorsal 9–14; anal 14–16; pectoral 12–14.
Vertebrae: 40 (1 specimen).

Body shaped in all respects as in *lamprotaenia*, its greatest depth 5.7–6.6 in SL. Caudal peduncle 3.2–4.0 in head.

Scales as in *lamprotaenia*, except that there appear to be a few more in a lateral series.

Head low, with exceedingly numerous mucous canals and pores, its length 3.7–4.0 in SL. Snout equal to, or more usually a little shorter than, eye, 3.2–3.8 in head. Eye 2.9–3.5. Interorbital 5.5–7.1. Maxillary narrowly rounded posteriorly, generally reaching vertical from anterior margin of pupil, 2.45–2.6 in head. Mandible slightly included, about coterminal with the snout, 2.0–2.2 in head. Gill rakers very close-set, those at angle rather more than half of length of eye. Teeth apparently in all respects as in *lamprotaenia*.

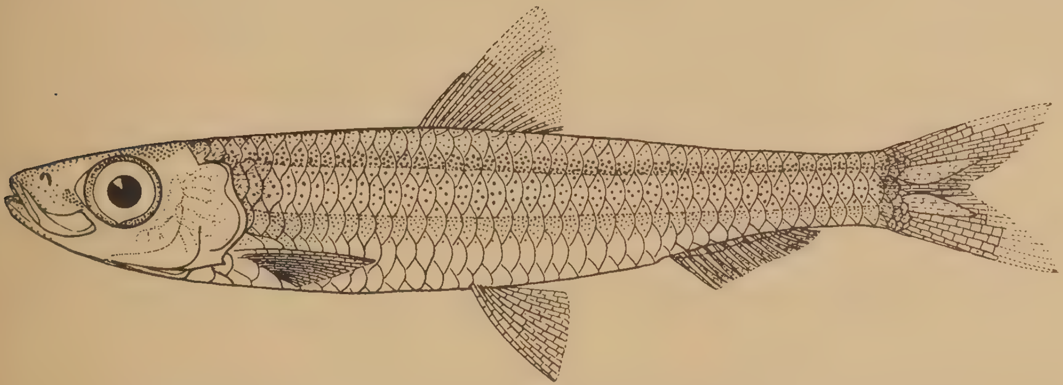

Figure 65. *Jenkinsia viridis*, 45 mm TL, from Bermuda, USNM 100546. After Rivas.

Dorsal fin elevated anteriorly, the longest rays reaching far beyond tip of last ray if deflexed, the fin generally beginning about half of an eye's diameter nearer to margin of snout than to base of caudal, the distance from margin of snout 2.0–2.25 in SL. Caudal fin as in *lamprotaenia*. Anal lower than dorsal, its origin about equidistant between insertion of pelvic and base of caudal, its base 1.8–2.2 in head. Pelvic fin only a little shorter than pectoral, inserted under the 4th or 5th dorsal ray and about equidistant between anterior margin of eye and base of caudal, its length 1.55–2.2 in head. Pectoral fin pointed, inserted a little nearer to tip of mandible than to base of pelvic fin, 1.55–1.8 in head.

Color. In all respects as in *lamprotaenia*.

Size. The largest specimens at hand, 55–58 mm TL (2.2–2.3 in.), may be near the usual maximum length attained.

Food. Although no specific information is at hand, there seems to be no reason to believe that the food of this species differs from that of *lamprotaenia*.

Enemies. No enemies have been listed. However, there can be no doubt that predatory fish and water birds feed on this species as they do on *lamprotaenia*.

Relationships. As stated in the account of *lamprotaenia*, the two species of this genus recognized herein are closely related. But they differ in the number of gill rakers on the lower limb of the first arch, *viridis* having 27–30 while *lamprotaenia* has only 19–24 (usually 20 or 21). That there is a difference between the species in the insertion of the pelvic fin, as stated by Rivas (*108*: 3), I am unable to substantiate, as it seems to be obliterated by the variations among specimens. However, according to four *viridis* and seven *lamprotaenia* that remain almost fully covered with scales, in the former 39–41 oblique rows of scales cross the lateral band between the margin of the opercle and the base of the caudal, whereas in the latter only 33–37 series cross this band. The specimens of *viridis* at hand have much more prominent mucous canals and pores about the head and on the anterior part of the body, but they may not be specifically significant.

It so happens, then, that even though T. H. Bean placed this species in the wrong genus and family (*Stolephorus*, family Engraulidae), his species still remains valid (*9*: 22).

Commercial Importance. This species is not known to be of direct commercial importance. It has been reported as exceedingly common in Bermuda (*9*: 123; *11*: 37), therefore it must be valuable as a forage fish.

Range. Known only from Bermuda and vicinity. It congregates in schools like *lamprotaenia* but ventures some distance offshore, as shown by the GRAMPUS catch noted above.

Synonyms and References:

Stolephorus viridis Bean, T. H., Proc. biol. Soc. Wash., *25*, 1912: 122 (orig. descr.; type local. Bermuda; types USNM 74084; common).

Jenkinsia stolifera Nichols (not of Jordan and Gilbert), Proc. biol. Soc. Wash., *33*, 1920: 63 (*Stolephorus viridis* in synon.).

Jenkinsia lamprotaenia Beebe and Tee-Van (not of Gosse), Field Bk. Shore Fish. Bermuda, 1933: 37, fig. (field char., diagn., distr.); Beebe and Tee-Van, Zoologica, N. Y., *13* (7), 1933: 136 (refs., *Stolephorus viridis* and *J. stolifera* in synon.; Bermuda); Hollister, Zoologica, N. Y., *21* (4), 1936: 276, figs. 40–44 (caudal skel.).

Jenkinsia bermudana Rivas, Smithson. misc. Coll., 106 (14), 1946: 1–4, 1 fig., 1 pl. (orig. descr.; type local. Bermuda; type USNM 100546; cf. *lamprotaenia*; but *S. viridis* Bean apparently overlooked, of which *bermudana* becomes a synon.).

Genus *Clupea* Linnaeus 1758

Clupea Linnaeus, Syst. Nat., ed. 10, 1758: 317; type species by implication (unquestioned), *Clupea harengus* Linnaeus.

Generic Synonym:

Rogenia Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 340; type species by monotypy, *Rogenia alba* equals *Clupea harengus* Linnaeus 1758.

Characters. BODY quite elongate, compressed. BONY SCUTES on median line of chest and abdomen, weak. SCALES with crenulate membranous borders. MAXILLARY with a large paddle-shaped supplemental bone. TEETH on vomer permanent, forming a small patch. Dorsal fin rather small, without a produced ray. Pelvic commonly with 9 rays, rarely with only 8.[8] Vertebrae 45–57.

Remarks. The very slender body and the presence of vomerine teeth distinguish this genus from other genera of the western North Atlantic.

Range. North Atlantic and North Pacific, ranging on the American side of the Atlantic from North Carolina to Greenland and in Europe from the Strait of Gibraltar to Spitsbergen. In the Pacific, the genus is represented from southern California to the Aleutian Islands and across to Siberia and Japan. A single species occurs in the western North Atlantic.[9] The species generally occurs in schools, which are usually seen at or rather near the shore.

Clupea harengus Linnaeus 1758

Atlantic Herring, Sea Herring, Herring

Figures 66–68

Study Material. At least 18 specimens, 75–270 mm TL, 63–224 mm SL, and smaller specimens, including postlarvae; from Kings Creek (tributary to Tangier Sound), Chesapeake Bay, Maryland; Ipswich River (estuary) and Woods Hole, Massachusetts; Sheepscot River and Eastport, Maine; St. Lawrence River; Nova Scotia; New Brunswick; and Newfoundland. This American material was compared with specimens from Norway and Sweden, and with specimens from the Pacific collected in California, Oregon, and Alaska.

Distinctive Characters. The following conspicuous field marks separate the postlarval and adult Atlantic Herring from the shads (*Alosa*) and from representatives of *Pomolobus* (alewives, hickory shad): the point of origin of its dorsal fin is about midway of its trunk (considerably farther forward in the others); its body is not as deep, a difference shown better in the illustrations than by words; and the sharp midline of its belly is less strongly serrate.

[Critical examination is required to distinguish the early stages of clupeoids of the western North Atlantic, one from another. Larvae of other species with which the Herring larva might be confused are the launce (*Ammodytes*), the so-called rock gunnel (*Pholis*), the capelin (*Mallotus*), and the smelt (*Osmerus*). But the position of the anus, about 83 % of the way back along the body, sets the larval Herring apart from all of these (about 75 % of the way back in *Mallotus* and *Osmerus*, about 66 % of the way back in *Ammodytes* and *Pholis*).—H. B. B.]

Description. Proportional dimensions in per cent of standard length, and counts, from specimens in *Study Material*, not including small specimens except for mention of their much more slender body and fewer gill rakers; specimens 63–224 mm SL.

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[8] Pelvics with 7 or 8 in South American species.—G. S. Myers.

[9] The genus *Clupea* in the present sense is also represented in Australian–New Zealand temperate waters and in southern South America. Norman has reviewed the South American forms (*102*: 37).—G. S. Myers.

Body: depth 20–25.8.
Caudal peduncle: depth 7.2–10.
Head: length 22.6–26.4.
Snout: length 5.6–7.1.
Eye: diameter 5.3–7.7.
Interorbital: width 3.0–4.5.
Maxillary: length 10.2–12.3.
Pelvic fin: length 9.4.–11.3.
Pectoral fin: length 14.2–17.7.

Scales: *ca.* 56–62.
Ventral scutes: *ca.* 39–46.
Gill rakers: 37–52.
Fin rays: dorsal 16–20, usually 17–19; anal 16–20, usually 17 or 18; pectoral 17–19.
Vertebrae: 55–57 (12 specimens).

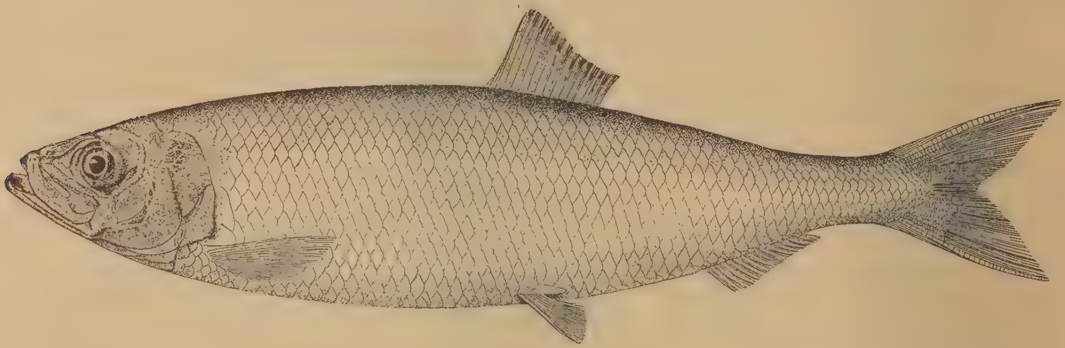

FIGURE 66. *Clupea harengus*, 315 mm TL, 12.62 inches, USNM 16667. Drawn by H. L. Todd.

BODY compressed, its greatest thickness somewhat less than half of its depth, its depth 3.9–5.0 in SL, much less in very young, 5.2–9.5 in specimens 40–70 mm.

SCALES only moderately adherent, often lost, especially in small fish; scales with crenate membranous border; about 16 or 17 longitudinal rows between ventral edge at base of pelvic and anterior ray of dorsal. VENTRAL SCUTES weak, often difficult to count, about 26–33 in front of pelvic fin and 13–15 behind.

HEAD 3.8–4.4. SNOUT 3.25–4.1 in head. EYE 3.4–4.25. INTERORBITAL 3.0–4.5. MAXILLARY rounded posteriorly, generally not quite reaching middle of eye, 2.0–2.3 in head. GILL RAKERS at angle nearly as long as eye in adults, proportionately shorter in young; increasing in number with age, the principal increase taking place before the specimens reach a length of 100 mm; specimens 36–70 mm long with only about 25–36 on lower limb. TEETH missing in upper jaw; the margin of maxillary with minute serrae; lower jaw anteriorly with about 6 rather prominent teeth on each side; middle of tongue with an elongated patch of small teeth; vomerine patch elongate, the teeth rather few and fairly strong.

DORSAL fin little elevated anteriorly, with nearly straight margin, its origin somewhat in advance of pelvics, usually nearer to base of caudal than to tip of snout. CAUDAL with lower lobe rather longer than the upper one, about as long as head. ANAL very low, its origin about equidistant between base of pelvic and base of caudal. PELVIC very near ventral edge, inserted equidistant between base of pectoral and last anal ray, 2.2–3.0 in head. PECTORAL inserted a little higher on side than pelvic, and below distal margin of opercle, 1.3–1.6 in head.

Color. According to Bigelow and Welsh (*16*: 93):

> Peritoneum quite dusky. Deep steel blue or greenish blue on the back with green reflections; the sides and belly silvery; the change from dark to pale sides often marked by a greenish band. The gill covers sometimes glisten with a golden or brassy gloss; indeed, fish just out of the water are iridescent all over with different hues of blue, green, and violet, beauties that soon fade, however, leaving only the dark back and silvery sides. The ventral and anal fins are transparent white; the pectorals, however, are dark at the base and along the upper edge; the caudal and dorsal dark grayish or shading into blue or green.

Size. The maximum size attained by the Atlantic Herring is about 450 mm (18 in.), though the usual size is only about 300 mm (12 in.).

Scope of Following Account. Much has been written about this Herring's spawning habits, food, rate of growth, seasonal migrations, and so on, by both European and American authors. Summaries of the literature about this species on the American coast, with frequent references to the European literature, have been given by Bigelow and Welsh (*16*: 92–105) and by Bigelow and Schroeder (*15*: 88–100), who drew heavily on important papers by Moore (*95*: 387–442), Lea (*78*: 75–164), and Huntsman (*63*: 165–171); furthermore, they were able to add much to the already known facts from their own studies. A review of all the literature would make this account much too long for the present work. Therefore, only a brief summary of what is known about its life history, drawn in large part from the accounts mentioned above (*15*; *16*), is given here. Nearly all of the papers cited provide bibliographies from which references to literature containing additional information may be obtained.

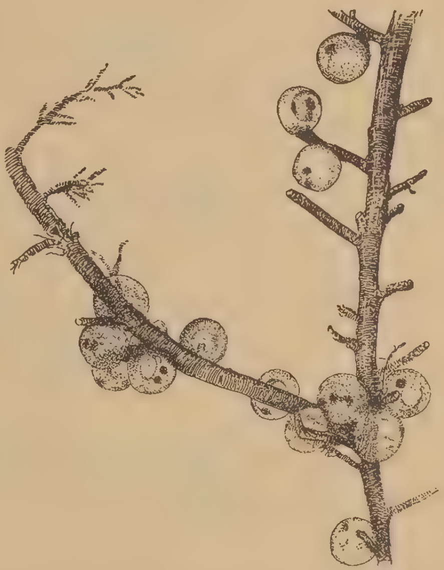

FIGURE 67. *Clupea harengus* (Europe) eggs attached to seaweed. After Ehrenbaum.

Development and Growth. The eggs of the Atlantic Herring, 1.0–1.4 mm in diameter (*16*: 98) or 1.2–1.5 mm (*29*: 362), are heavier than sea water, and adhesive, adhering singly or in clumps to objects in the water or to the bottom. If they fall on muddy bottom they probably smother.

The number of eggs produced by a single female is relatively small, and as usual it varies according to the size of the fish, large fish having many more eggs than small ones. The number produced by one female may vary between 21,000–47,000 (*101*: 283) or between 20,000–40,000 (*16*: 94).

The duration of incubation depends upon the temperature. Norman stated that eggs kept at 52–58°F hatched in eight or nine days, whereas others held in water at

32°F hatched in 47 days (*101*: 330). Bigelow and Welsh gave 10–15 days as the probable average incubation period for the usual temperatures prevailing in the Gulf of Maine during the hatching season; these seem to vary between about 46–55°F (*16*: 94).

The newly hatched fish, transparent and very slender, vary considerably in length, with a range of about 5.3–7.0 mm (*29*: 362) or about 5.0–6.0 mm (*16*: 97). The small yolksac is absorbed in several days, when the larvae have attained a length of 8–10 mm; no marked changes take place in the form of the body during this time. The vent is situated so far back that the length posterior to it is less than a fifth of the total body length, and the depth at this size is contained about 24 times in the total length. Considerable advancement in the development of the fins was evident in larvae around 19 mm long, taken in the tow at Helgoland; rays definitely were present in the dorsal and caudal, and the caudal had a concave margin. However, the anal and pelvic fins did not become differentiated until a length of about 29 mm was attained. In young about 41 mm long, the proportionate depth of the body has increased greatly, and the vent as well as the anal and pelvic fins have all moved forward; larvae of this size are said to be in the transition stage. However, this stage may be attained by the spring fish at a length of 31–44 mm, and by the fall fish at 44–60 mm (*29*: 363–366, figs. a–g).

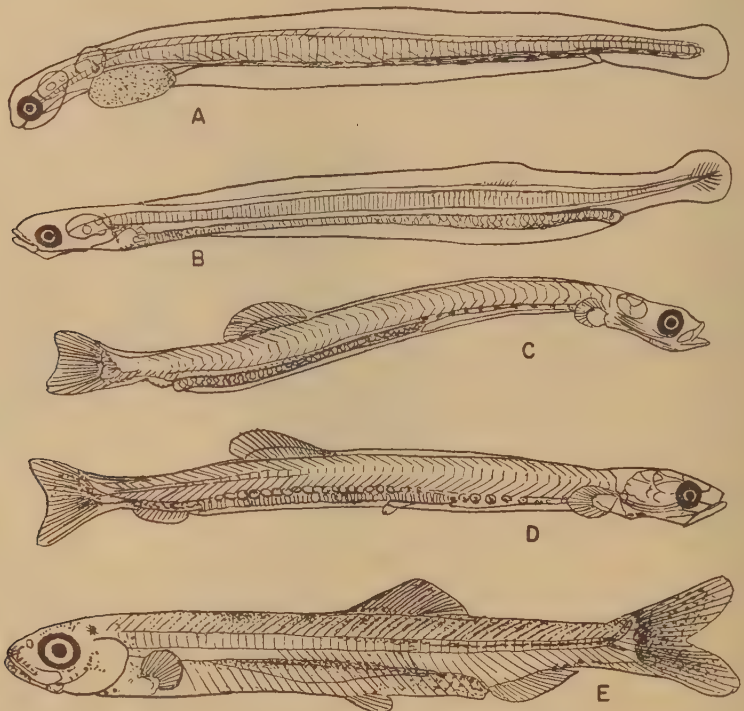

FIGURE 68. *Clupea harengus* (Europe). A–D, larval stages; A 7 mm; B 10 mm; C 19 mm; D 29 mm; E young fry, 41 mm.

Young fish from the Clyde Sea area of England lost their yolksac and began developing the dorsal fin at about 10 mm; the end of the notochord turned up at about 17 mm; pelvic fins appeared at about 22 mm; the caecal part of the stomach began to form and the air bladder became prominent at a length of 30–35 mm; and the least length at which metamorphosis took place was 42 mm (*91*: 248, 252). Marshall, *et al.* also recorded a regular weekly increase of 3 mm prior to metamorphosis, at a length of about 35–40 mm. This rate of growth of the larvae is in fair agreement with that reported for elsewhere in Europe.

Huntsman observed that, on the American coast, as at Grand Manan Island, New Brunswick, larvae hatched in late summer and early autumn had attained a length of 17–20 mm by the end of November or early in December. Fry 50–60 mm long were abundant in St. Andrews Bay in June. Yearlings were 90–125 mm long in the fall of the year in the Bay of Fundy. This rate of growth is in agreement with that observed by European investigators in examples from Norwegian waters and from the North Sea. A one-year old Atlantic Herring, then, is about 88–125 mm long.

These fish do not fall into definite size groups when more than one year old. But their subsequent rate of growth may be determined by segregating the fish into year-classes through scale reading, for the so-called winter rings are so pronounced that they can be relied upon with considerable confidence to show the age of the individual specimen.[10] Thus, Meek (*93*: 76) has indicated the following average lengths for those caught on the Dogger Banks in the North Sea: 98 mm at one year, 183 at two, 220 at three, 241 at four, 255 at five, 266 at six, 275 at seven, 281 at eight, 287 at nine, 291 at ten, 293 at eleven, and 295 mm at twelve years of age. The Norwegian fish spawned in 1899 grew more slowly at first than the Dogger Bank fish but about equaled the latter in size by their sixth year. Fish up to 19 years old have been found in many Canadian samples (*83*: 10) and some 20 years of age have been seen in Europe. However, the rate of growth after age 12 is extremely slow. According to observations by Huntsman and by Lea, the rate of growth is about the same for Atlantic Herring both here and in Europe, with Bay of Fundy fish growing a little faster than those spawned in the Gulf of St. Lawrence, and with the fish spawned along the outer coast of Nova Scotia growing a little faster than those produced in the Bay of Fundy.

On the coast of Maine, some individuals reach sexual maturity at a length of about 235 mm (9.5 in.), when three or four years old. Usually they do not spawn until they are 250–262 mm (10–10.5 in.) long, at five to six years of age. Most of the individuals in the schools of spawning fish are 300–325 mm (12–13 in.) long, the majority of which is then perhaps 10 years of age or more. It is believed that Atlantic Herring, after reaching sexual maturity, spawn every year as long as they live.

Atlantic Herring may be divided roughly into three growth stages,[11] each with its own general distribution and seasonal migration. The first stage, the "sardine," consists of one- and two-year-old fish 45–200 mm long; the second is the "fat" stage, consisting of sexually immature fish about two years old, 190–200 mm long; and the third or "spawn" stage is a mature fish (see also pp. 283, 284).

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[10] For a detailed study of the scale of the Atlantic Herring in relation to growth, see Lea (*78*:81–93).

[11] Sometimes a greater number of growth stages has been recognized. Thus, Johnson (*69*:351), following the nomenclature of the fishermen of Passamaquoddy Bay, listed "brit" 80–100 mm, "snippers" 110–130 mm, "oils" 140–180 mm, and "mustards" 190–230 mm. In New England at least, the term "sperling" is used for young fish 75–125 mm long; they therefore come within the range of the sardine group, as used by Bigelow and Welsh (*16*:99).

Spawning Seasons. Spawning takes place in the spring, summer, or autumn, or in both spring and autumn, depending on the locality. Apparently there is no time in the year when spawning, off Europe at least, does not take place somewhere. On the southern coast of Newfoundland and in the Gulf of St. Lawrence, they are spring spawners, commencing in May or even as early as the latter part of April. In the southern and inner part of the Gulf as a whole, the season lasts only a few weeks. But on the south coast of Newfoundland, and perhaps on the west coast as well, spawning may continue until July, and some fish spawn in the Gaspé-Bay of Chaleur region in September. To the south, on the Atlantic coast of Cape Breton, Nova Scotia, spawning occurs chiefly in May or June, but also in August and September; and on the outer coast of this province to the south of Halifax, from August through September (*95*: 405; *60*: 10; *83*: 11, fig. 6).

The Bay of Fundy once harbored both spring and summer-autumn spawning schools, as did the outer coasts of Nova Scotia (by fishermen's reports); but they seem never to have been numerous; it is doubtful whether any of the spring spawners still exist anywhere south of the Gulf of St. Lawrence. At the mouth of the Bay of Fundy and off the easternmost part of the Maine coast, the heaviest spawning takes place in July-August and September in some years, with spawning continuing late in the fall; but in other years it does not commence until August, to end early in October. Passing westward–southward, the spawning run is progressively later and shorter: from mid-August until October in the general vicinity of Mt. Desert Island; in October along the east coast of Massachusetts (where only a few spawn); and early November near Woods Hole, Massachusetts.

Off northern Europe, where two principal races are recognized, namely coastal herring and sea herring, the coastal fish spawn mostly in brackish water and principally in the spring months, whereas the sea herring spawn in the open sea over widely distributed times of the year, but mostly in the late summer, autumn, and winter. The spawning periods of the different stocks are so varied that one may find spawning fish somewhere at almost any time of the year (*29*: 362). The Pacific Herring has only one spawning period, which may vary between December and June; the earliest spawning takes place in California and the latest in northern Alaska (*111*: 278).

Spawning Grounds and Depths. In northern European waters, as already indicated, at least some fish spawn in shallow inshore brackish water whereas others spawn in the open sea. But in the western side of the Atlantic they are not known to spawn in water less saline than about 31.9 ‰ or more saline than about 33 ‰. In the Gulf of Maine, spawning takes place at temperatures of about 46–55°. For the more northern part of the American range, however, precise information in this regard is lacking.

Off America, Atlantic Herring spawn in greater or fewer numbers throughout their geographic range, from north to south. Around Newfoundland they spawn chiefly within the bays. However, from the southern side of the Gulf of St. Lawrence southward as far as southern Maine there is no considerable sector of the coast, except a part of the Bay of Fundy (p. 290), that does not see a more or less plentiful spawning run. Moore has spoken of the northern coastline of the Gulf of Maine as "a continuous spawning ground," succeeded by scattered grounds wherever the bottom is suitable, extending as far southward as Block Island off the Rhode Island coast (*95*: 408). However, local spawning grounds may be abandoned for a term of years—a common occurrence (*95*: 430).

In the Gulf of St. Lawrence, Canada, they have been described as spawning in water so shallow that the eggs are sometimes washed up on the beach by the waves (*95*: 411), as happens every year in northern European waters (*15*: 99). In general, however, our Atlantic Herring spawn at depths of, say, 2–30 fms. Thus spawning takes place both along shore and on the various ledges that lie between 5–25 miles off the coast, where eggs are often found sticking to the anchor lines of fishing vessels. But the nature of the bottom makes it improbable that any eggs are laid at a depth greater than 75 fms. on the American side, though spawning at a depth of 100 fms. has been reported for Scandinavian waters (*95*: 411). Whether, or how regularly, the fish may spawn on the shallower parts of the offshore fishing areas, from Georges to Grand banks, remains to be learned.

Habits.[12] Herring are primarily wanderers of the open sea. While they also enter bays and estauaries freely, they seem never to have been reported reliably from water that is more than slightly brackish; along the American coast a salinity of perhaps 2.8 $^0/_{00}$ is about the lower limit of tolerance.

As a rule, all sizes of Atlantic Herring congregate in schools of hundreds or thousands of individuals, with a given school usually consisting of individuals of about the same age and size. How long a school may preserve its identity as such is not known, for while Fridriksson and Aasen have found that specimens tagged and released together may be recaptured at widely separated localities (*40*: 22), this may not apply to schools that have assembled under natural conditions.

When a school is at the surface in the daytime, as often happens in calm weather, it is betrayed by a fine rippling of the water; but the fish do not ordinarily "fin" or lift their noses above the water, as is characteristic among menhaden (p. 354). At night they are betrayed at the surface by their luminous trails if the water is "firing."

A school of Atlantic Herring is not as easily frightened as a school of mackerel by an approaching boat. Neither is it usual for them to leap clear of the water, except when young fry are pursued from below by larger pelagic fish.

A school that is actively feeding is likely to be more or less stationary, drifting as a whole with the current. At other times schools are seen traveling as if with purposeful intent, all of the members swimming side by side in the same direction. Schools of sardine-sized fry may often be seen streaming past some rocky headland, seemingly in an endless procession. What the directive stimulus may be we have yet to learn, for as Huntsman has pointed out, "There is no indication that herring swim against the current unless the water is somewhat turbulent" (*65*: 83). Whether they make or lose headway over the bottom while doing so depends on their swimming speed relative to the strength of the current.

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[12] Condensed from Bigelow and Schroeder (*15*: 89).

No information is available as to how rapidly a school may travel at sea. But Fridriksson and Aasen have found that specimens held alive in nets swam constantly at a rate of about 0.2–0.25 sea miles per hour (6–8 m/min.) when not disturbed. It is certain that they are capable of long journeys, for individuals tagged on the east coast of Iceland have been recaptured in southern Norway, and vice versa (*40*: 26, 27).

How active Atlantic Herring are at any time and place depends primarily on the water temperature. In the Bay of Fundy region, for example, they "move very sluggishly when the water is coldest, in February and March," i. e. when the upper 20 fms. or so have cooled to about 32–36°. They become active again when the water has warmed to about 40–43°.

While the vertical range of this species extends down to an extreme depth of about 100 fms., the vast majority lives at depths shallower than 40–50 fms., living pelagically in the upper water layers for most of the year but close to the bottom during the coldest months.

Relation to Light. That light is an important factor in controlling their vertical distribution, at least in southern New Brunswick, was discovered by Johnson in 1939 (*69*: 349–354). He found that at night, in the absence of appreciable light, all sizes were quite near the surface. During weak light, as at dawn and dusk, all sizes still were a foot or so from the surface. However, as the sun rose above the horizon they left the surface, the largest fish, 190–230 mm long, descending to a depth greater than 10 feet and those 140–180 mm long to a depth of 10 feet or more; the smaller ones in general were nearer the surface. Also, on cloudy days all sizes were closer to the surface than on clear days.

Migratory Movements. Because of the economic value of this species, knowledge of the migrational habits, which would make it possible to predict runs in advance of their occurrence, has been and continues to be sought on both continents. In Europe at least, these studies have been complicated by the presence of a large but indeterminate number of local populations or races (p. 287), each with its own migratory pattern, a fact not known until comparatively recently and even now not well understood. As Norman (*101*: 263) wrote:

> At some seasons herrings may be found in huge numbers in a given locality (in Europe), at others they will disappear almost entirely; in other places they may be caught all the year round, but the numbers caught on a given ground may exhibit an immense amount of variation from one season to another.

To explain these long known and very obvious facts, an older view, widely held until about 1825, was that Atlantic Herring as a whole withdraw in winter to Arctic waters, to return to more temperate coasts in spring, some of them to the eastern side of the North Atlantic, others to the western side (for further details, see Meek, *93*: 67–87). But Perley wrote as early as 1852 that this idea was "supposed to be wholly imaginary," it being generally believed then "that the herring fattens in the depths of the ocean, and approaches the shore in shoals merely for the purpose of depositing its spawn" (*104*: 206). Successive and long continued studies at many hands have since proven that in reality we are not dealing with any widespread mass migrations, but with short-range movements (inshore and offshore) of local bodies of fish, each with its own area of occurrence and each of which may include subpopulations that spawn at different times of year, as Norman has pointed out. It is equally clear that the ranges of the races of European fish overlap—highly probable at least that more or less interchange is constantly taking place between adjacent races.

However this may be, the basic migratory pattern, essentially the same for all of them, may be conveniently divided into the three successive phases noted previously—sardine, fat, and spawn.

Those of the sardine stage, 45–200 mm long, tend to remain near their birthplace. They probably spend the winters on the bottom in a few fathoms, appear in the inshore waters of New England, New Brunswick, and Nova Scotia in the spring as one- and two-year-old fish, and remain there through the summer and autumn. How far they may journey during this period and in what direction depends chiefly on the movements of the water. For example, every summer untold millions of sardines congregate in the Passamaquoddy region at the entrance to the Bay of Fundy (p. 290), and it is now known[13] that the responsible factor is the prevailing movement shoreward of the subsurface water in which the sardines are swimming; this shoreward flow is motivated by the offshore movement of surface flow from tributary streams combined with superficial offshore currents set up by the wind. Sardine-sized fish, in other words, drift with the current much as do any planktonic animals, such as the euphausiid shrimps and copepods on which they feed. In technical language, they are denatant, which applies equally wherever young Atlantic Herring are produced.

The fat stage consists of sexually immature fish about two years old and 190–200 mm long that have accumulated a large amount of fat around the viscera and among the body tissues. During the year's period that precedes their sexual maturity, they disperse much more widely than do the sardines. Whether this wide scattering is brought about wholly by transport of water movements or whether directive swimming plays an important role remains a mystery. In either case they are encountered anywhere and everywhere throughout the range of this species. In the Gulf of Maine, for example, where more attention has been paid to the movements of these fish than has been the case anywhere else in the western North Atlantic, the fat stage has been encountered indifferently close to shore, as at the mouth of the Bay of Fundy in the northeast, and offshore in the Massachusetts Bay region in the southwest, in the central parts of the Gulf, and over Georges Bank. Those picked up during the warmer months either in mackerel seines or in otter trawls are mostly very fat and show no signs of approaching sexual maturity. It seems that these "fat" fish, like the sardines, merely sink down close to the bottom for the winter wherever they may be.

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[13] Studies carried out from the Atlantic Biological Station at St. Andrews, chiefly under Dr. A. G. Huntsman's leadership (*65*:95, 96).

About all that is known of the mature spawn stage in the western Atlantic is that these fish live mostly some distance offshore near bottom and appear in vast numbers in their spawning areas at spawning time. In the Gulf of Maine, most of them seem to drop out of sight after having spawned; the large ones caught there out of spawning season fall in the fat category. But there is no reason to suppose that they travel far during the interval (between spawning time and winter) when they are feeding greedily to recover condition sufficiently for spawning again the next year. In fact, it is probable that they, like the other two stages in the Gulf of Maine, merely descend into deeper water to winter, as has long been known to be their custom in European waters. How deep the great body of them may go is not known, but the contour of our continental shelf is such that no fish need swim any great distance to reach water deeper than 50–75 fms. anywhere between Cape Cod and the Gulf of St. Lawrence. It seems likely also that they spend the winter in deep water in the southern part of the Gulf of St. Lawrence, but definite information in this regard is lacking. On the southern and western coasts of Newfoundland, however, where spawning takes place in the spring, the mature fish "move off into deeper water in summer" (*125*: 35) but return late in the autumn to their natal bays, where they have long supported important November–January fisheries.

Food and Feeding. Atlantic Herring feed on plankton—first on diatoms and other unicellular organisms, then on copepods and their eggs following the yolksac stage (*91*: 252). In summing up her rather extensive investigations at Plymouth, England, Lebour (*79*: 463) listed the following by stages of growth; before disappearance of the yolksac: larval gastropods, green food (probably diatoms and flagellates), larval bivalves, nauplii and other young stages of small crustacea, as well as the eggs; after disappearance of the yolksac up to about 12 mm: the same, but with small adult copepods added; after 12 mm and probably until metamorphosis: copepods; after metamorphosis: copepods, decapod crustaceans, amphipods, and fish.

Only two kinds of food were found in about 1500 examples taken off Eastport, Maine (*95*: 401). Moore said that "One of these [foods] consisted of copepods ('red seed'), which appeared to constitute the sole food of the small herring, the so-called brit, and a considerable portion of that of the larger individuals from 5 1/2 inches upward." But the principal food of the larger fish was euphausiid crustaceans (*Meganyctiphanes norwegica*), known to local fishermen as "shrimp." These are so important in the diet of this species that it seems likely that the appearances and disappearances of large fish in the open waters of the Gulf are correlated with the presence or absence of euphausiids of one kind or another. Concerning their capture, Moore remarked:

> To capture such prey requires some address on the part of the herring; they frequently throw themselves almost clear of the surface and their splashings... are audible at a considerable distance. When feeding on copepods the movements of the herring are less impetuous. They swim open-mouthed,[14] often with their snouts at the surface crossing and recrossing on their tracks and eventually straining out the minute crustaceans by means of their branchial sieves.

The sieves were described by Moore (95: 401) as follows:

> An examination of the mouth cavity of the herring will disclose a series of long bristle-like processes, the gill rakers, projecting from the anterior face of each gill arch, like the teeth of a comb. When the mouth is opened widely the tips of the gill rakers stand apart, but when it is closed or partly closed they become more closely approximated and each series is pressed closely against the inner face of the series attached to the arch next in front. There is thus formed a beautifully fine and effective sieve, capable of retaining small bodies contained in the water taken in at the mouth and discharged through the gill slits.

The amphipod genus *Euthemisto* is also an important food for this species off Europe; that this is not so in the Gulf of Maine no doubt reflects the scarcity of this pelagic crustacean in our coastal waters. In default of an abundant supply of crustacea, and sometimes even when these are plentiful, the fish feed on whatever other kinds of smaller planktonic animals and plants may be available. Small fish of various kinds have been found in their stomachs: capelin, especially in Newfoundland waters in winter; and grass shrimps (*Crago*), schizopod shrimps (*Mysis*), amphipods (*Gammarus*), small squid, annelid worms, and crab larvae at Woods Hole, Massachusetts. But the smaller planktonic plants, whether diatom or peridonidian, have never been found in specimens longer than 15 mm, probably because their gill sieves are not fine enough to retain them.

Enemies. Their chief natural enemies include all kinds of marine predators, such as cod, pollock, haddock, silver hake, mackerel, dogfish and other sharks, finback whales, and the common squid (*16*: 104). An attack on a school of young Atlantic Herring by squid has been described by Hildebrand and Schroeder (*59*: 82) as follows:

> We had occasion to watch the wholesale destruction of 2 to 4 inch herring during June 1925, on the flats about Provincetown, Mass. Schools of 10 to perhaps 50 squids circled around a school of herring until they had bunched their prey into a compact mass. Individual squids then darted in and seized one, sometimes two, and then darted back for more. Along the beach there remained a silvery streak of dead herring.

A similar firsthand account of silver hake (*Merluccius bilinearis*) driving a school of large Atlantic Herring up on the beach in Massachusetts Bay has been reported (*15*: 90).

Parasites. Among the European fish, "cestode larvae and trematodes were frequently found as parasites in the gut. The latter were common and the incidence appeared to increase as the herring grew, as many as 29–30 per cent being parasitized in the large catches of May 21 and 30. Cestode larvae were less numerous, and they too were more frequent in the older fish" (Marshall, *et al.*, *91*: 253). No fatalities were specifically ascribed to these parasites; Sindermann and Rosenfield have found that infestation with trematode larvae may be fatal—at least under experimental conditions—"provided they are present in numbers large enough to overwhelm the host" (*117*: 12). Furthermore, it has been reported that nematodes, cestodes, and trematodes occur in the viscera and sporozoa in the muscles of small fish taken at Woods Hole, Massachusetts (*85*: 473).

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[14] That the larger herring "swim open-mouthed" when feeding on copepods has been questioned by Battle, *et al.*, who are of the opinion that the fish seize the organisms individually (7:411). However, as to the organisms ingested there is general agreement.

Mass Mortalities and Diseases. The literature that deals with the Atlantic Herring contains many accounts of their great destruction on both sides of the North Atlantic. For June and July 1914, Cox reported widespread mortality on both the southern and western sides of the Gulf of St. Lawrence (*28*: 82–85). A few years later, a spectacular event occurred in Cohasset Harbor, Massachusetts Bay, on October 5, 1920, when an estimated 20,000 barrels of fish 100–125 mm long became stranded on the mud with a falling tide (*16*: 104). On October 10 a second but smaller run and on October 15 a run as large as the first were stranded similarly. The exact reason for the stranding and mass destruction was not determined, but fishermen thought that the fish had been driven into the nearly landlocked harbor by silver hake, *Merluccius bilinearis*. Other mass strandings of small individuals have also been reported, for Manchester Harbor, Massachusetts (*14*: 327). Pursuit by predatory fishes is the most likely cause of simultaneous mass strandings within small areas; for an eyewitness account of one such event, see page 285.

But enough evidence has now accumulated to make it practically certain that when mortality is very widespread it has been caused by disease of one kind or another. Thus Cox found that fish from the Gulf of St. Lawrence case of 1914 (above) were so evidently in a diseased condition and were so heavily infested with a myxosporidian protozoan that it seems practically certain that the latter had been responsible for the mortality (*28*: 82–85). It is known now that those along the coasts of New England, and presumably in more northern waters, suffer from fungous disease caused by *Ichthyosporidium*, from ulcer disease caused by protozoa, from pigment spot disease caused by larval trematode worms, and from tail rot caused by bacteria; it is known also that fungous disease in particular, and probably the others as well, sometimes reaches epidemic proportions, with mortality so widespread and so severe that the sardine fishery is very seriously affected.[15]

Relationships. Although the Pacific herring has been recognized as being specifically distinct from the North Atlantic Herring and has for many years been designated *Clupea pallasii* Cuvier and Valenciennes, it is difficult in the light of rather recent studies to find distinguishing characters. This difficulty was pointed out by Rounsefell, who made some studies of the relationship himself and reviewed the findings of several European investigators (*111*: 243). The distinguishing character given by Regan in his revision of the Clupeidae is "Ventral scutes all keeled" in *harengus* and "Ventral scutes in front of pelvic fins not keeled" in *pallasii* (*106*: 227). According to the material now at hand, the scutes in *pallasii* are merely less strongly developed.[16]

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15. For a general survey, with photographs, of diseased fish, and references, see Sindermann and Rosenfield (*117*).
16. Relationships with the species of temperate southern hemisphere waters have not been adequately worked out. Regan, the most recent revisor, had inadequate material (*106*:228). Norman did not attempt to compare the South

Variations. It has long been generally appreciated that Atlantic Herring in the east do not constitute a homogeneous population, since a number of regional races is included (pp. 282, 283). Thus "it is possible," writes Norman, "to recognize North Sea, Baltic, Norwegian, Icelandic herring" (*101*). These races differ from each other in such morphologic characters as average proportional dimensions and average numbers of fin rays and vertebrae. But we ought to caution the nontechnical reader that these are numerical averages for many specimens and are not used for the identification of an individual specimen, or of even a few fish; only when the number of specimens examined is large are such figures significant. For example, if the average number of vertebrae was given as 56.3–56.5 for one locality and as 56.6–56.8 for another, it means simply that in the first case there were more fish with 56 vertebrae and less with 57; and in the second case, more fish had 57 and less had 56. No fish ever has a fractional number of vertebrae.[17]

Each of these races has its own chief center of abundance, its own pattern of seasonal migration, and its own spawning season or seasons, for some of the races include both early and late spawners. The races differ in the average size to which their members grow. A knowledge of the times and localities where these populations are catchable in greatest amount is of so much commercial importance that these matters are under continuous survey by the fisheries services of the countries chiefly concerned.

In 1914, Hjort found (*60*: 9–12) in the western Atlantic Herring: that the average number of keeled ventral scales is larger (13–14) for the autumn spawners of outer Nova Scotia and the Gulf of Maine than for the spring spawners of the Gulf of St. Lawrence; that the number of vertebrae is greatest (55–59, av. 56.8) in those from the west coast of Newfoundland; that the number of dorsal and anal rays averages higher in those caught in the open sea than in those from the more enclosed waters of the Gulf of St. Lawrence and Bay of Fundy; and that, among the spring spawning populations, the average number of vertebrae, fin rays, and keeled scales is higher in those from the west coast of Newfoundland than in those from the southern part of the Gulf of St. Lawrence. But the fishery for "fat" and for "spawn" fish plays so small a role in the general welfare of Canada and the United States (p. 288) that no additional information seems to have been contributed to the racial question on this side of the Atlantic. From analyses of extensive data, however, Day, Leim, and Tibbo showed that Canadian Atlantic Herring represent six more or less distinct populations, differing from each other in rate of growth and in average number of vertebrae: one in the northern part of the Gulf of St. Lawrence, a second in the Bay of Chaleur, a third in the southern part of the Gulf, a fourth off the outer Nova Scotian coast, a fifth along southern Newfoundland, and a sixth along western Newfoundland (see Leim, *83*: 11, figs. 6, 12).

Commercial Importance. From an economic standpoint, these fish are perhaps the most important in the world. In addition to their great value as food for man, many

American forms with the northern ones (*102*: 37). Regan's *Clupea holodon* from New Zealand is now known as *Clupea antipodum* (Hector).—G. S. Myers.

[17] For a general survey of the races of eastern Atlantic Herring, see especially Lübbert and Ehrenbaum (*89*: 14–19); for a detailed study of the average number of vertebrae in the different races, see LeGall (*80*: 167–170).

are used for bait, and they constitute an important item in the diet of other fish that are of great economic importance. The catches have fluctuated greatly from year to year, but they have not always provided a criterion of the supply available. In America, at least, the catches have often been governed by demand and profit. Therefore the fishing efforts from year to year have not been uniform. Through 1952, the annual catches on the American side have fluctuated between 172,000,000–359,000,000 pounds,[18] the major part of the catch from Canada and Newfoundland. The catch in Europe in 1948 was 4,150,000,000 pounds (1,881,713,000 kilo; *24*: 6), and in 1956, the latest year for which information is conveniently available, it was 5,858,650,000 pounds (2,590,715,000 kilo). European waters, in short, have yielded annually something like 15 times the catch (in pounds) taken in American waters. However, the apparent discrepancy in relative productivity does not loom so large when we note that the bulk of the American catch is concentrated within a latitudinal belt of about 8°30′ at most, while the European catch is distributed along something like 19°30′, or a distance nearly 2.5 times greater.

Small fish, 75–125 mm or so in length, are canned in large quantities as sardines, not only in Norway but along the easternmost coast of Maine and in the region of Passamaquoddy Bay at the mouth of the Bay of Fundy on the New Brunswick side; these last account for the concentration of Atlantic Herring landings there. Elsewhere the American catch consists chiefly of the "fat" and "spawn" stages. Some of the large ones are consumed fresh, others are salted or pickled, some are salted and smoked in various ways, and still others are canned.

The three principal types of smoked Herring are the kipper, bloater, and red herring. The kipper is split down the back, immersed in brine for a very short period of time, slightly dried, and then smoked for several hours. The bloater is cured without splitting, only the belly being cut open for cleaning; it is lightly salted and smoked only long enough to dry the flesh. The red herring, like the bloater, is not split, but it is much more heavily salted (buried in salt for at least five days) and then smoked for ten days or so. Thus the last is a fairly durable product, which can be shipped to distant markets, whereas the kipper and bloater are perishable. The several curing processes are practiced much more extensively in Europe than in America and are sometimes carried out aboard fishing vessels. Large quantities are also frozen, to be used as bait by the hand-and-long-line fishermen: for example, 32,000,000 pounds in Canada (including Newfoundland) in 1954. While corresponding information is not conveniently available for the United States, this time-honored method of fishing is now far outstripped by the otter trawlers. The landings by line fishermen in Maine and Massachusetts in 1954 were 9,000,000 pounds, the greater part of which was hooked on frozen herring. The offal at the canneries and occasionally surplus catches of whole fish are reduced to oil, fish meal, and fertilizer.

Fluctuations in Abundance and Catch; *Year-Classes*. It is notable that a fishery such as the one for this species in European waters, exploited for centuries, has apparently shown no positive or permanent decline. Of course it has been claimed from time to time that signs of exhaustion were evident, but such claims seem to have been based on the scarcity or disappearance of the fish in certain areas, not on the population as a whole. There certainly is insufficient information concerning the American stocks to furnish a basis for an answer. If a decline has taken place in American waters, it could scarcely be ascribed to overfishing, as the supply of fish generally has exceeded the demand. The fluctuations in the annual catches, then, do not necessarily mean that the fish were scarce when a small quantity was caught, or were abundant when a large catch was taken. Neither does a small annual catch necessarily indicate that the demand was light. It may mean only that the fishermen were operating in an area where the fish are usually abundant but were absent there that year. The fish are influenced in their migrations by the weather and by the presence of food, which seem to account for their abundance in one area one year and elsewhere the next. At present it is impossible to predict the time of arrival of schools in any given area.

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[18] Statistics from publications issued by the governments of the respective countries named.

From his studies of Atlantic Herring from the English Channel, Ford wrote, "if it could be shown that the variation from season to season followed some rule, it might yet be possible to discover that rule from the study of past data and hence to predict what is likely to occur in the future" (*36*: 369). But all uniformity seems to be lacking. "It can be regarded as certain that fishing results are dependent upon the weather, but in the present state of meteorological science, we cannot hope to receive much advanced information regarding weather conditions during a forthcoming season." Nevertheless, he found that daily forecasts had some value, for a gale warning not only indicated an interruption of operations, but it also suggested heavy catches when fishing was resumed. The prediction of calm weather, on the other hand, suggested lighter catches.

The many age analyses of Atlantic Herring, chiefly of those from European waters, have shown that a very large crop of young may survive in some years while very few do in other years, especially in more northerly spawning regions. Consequently, those spawned in a favorable year may dominate the population for several years to come. The classic example is the year-class produced in 1904 that dominated the Norwegian catches for the next six years and dominated catches on the west coast of Newfoundland until 1914 and even 1915. In the Gulf of St. Lawrence, of late years, the broods of 1939, 1941, 1943, and 1944 were highly productive, whereas those of 1940, 1942, and 1945 contributed but little to the population (*83*: 107). There is also the well-documented case of a particular body of Bay of Fundy fish that did not receive any significant recruitment for some 10 years, by which time the few remaining fish seem to have dropped out of the picture due to old age (*15*: 93, 99). Consequently, the successes or failures of reproduction in given years are reflected in the catches. Thus Ford (*36*: 370) was able to predict which year-classes would predominate in the catches of certain years, as well as the probable proportion of large fish, for as a rule old fish are larger than the younger ones, though the fish in some areas grow faster than those in others. Ford concluded his discussion on predictions as follows:

In practice it is possible to obtain advance information of the relative richness of broods and hence of the relative success of future fisheries. But there still remain possible influences which militate against a forecast of yield based entirely on this evidence, chief among these being the factors which govern migrations of herring.

Methods of Fishing. Most of the fish are caught in traps known as wiers, in floating traps, stop seines, purse seines, and drift nets; in the American bays and harbors, large numbers, especially of the smaller sizes, are taken by "torching," i. e. by netting fish attracted by a light.

Range. Atlantic Herring in American waters range from Greenland to North Carolina, but usually not in commercial abundance south of New Jersey; they are most abundant north of Cape Cod. In Europe, where certain races enter brackish water, they range from Spitsbergen, Novaya Żemlya, the Kara Sea, the White Sea, and northern Norway south to the Straits of Gibraltar.[19]

Occurrence in the Western North Atlantic. Stray specimens have been reported for as far south as Cape Hatteras, the lower part of Chesapeake Bay, Maryland, and New Jersey (*59*: 82; *119*: 120; *37*: 93); and only irregularly do a few visit the coasts of New York and Rhode Island. But they are seasonally abundant and generally distributed throughout the Woods Hole region, though not in any great numbers (*123*: 741). Although they appear sporadically in the Massachusetts Bay region, they are plentiful enough in some years to support local fisheries. Along the coast of eastern Maine, and in the Passamaquoddy region at the mouth of the Bay of Fundy,[20] they are not only far more plentiful but more regular in their comings and goings. But farther up the Bay of Fundy, on the New Brunswick side and at its head, they are far less plentiful, probably because of the turbidity of the water there. However, along the Nova Scotian side, toward the mouth of the Bay, they are sufficiently abundant so that they yielded between five and six million pounds in 1946 (Annapolis and Digby counties); indeed in the general vicinity of Yarmouth on the west coast of the province they are so plentiful that great numbers of giant tuna congregate there summer after summer to harry and destroy the schools in the local tide rips.[21] Thence eastward along the outer coast of Nova Scotia they are abundant and generally distributed; witness a reported catch between the vicinity of Cape Sable and Cape Breton of something more than 41 million pounds in 1946, and 21 million pounds in 1956, the latest year for which pertinent statistics are readily available.—H. B. B.

There are fewer, it seems, along the Nova Scotian shore line of the Gulf of St. Lawrence; landings there in 1946 were 1,330,000. But thence westward these fish are numerous again throughout the southern side of the Gulf,[22] around Anticosti Island (described there as in "bancs enormes"; *116*: 285) and along the Gaspé shore in the lower part of the St. Lawrence estuary. But they are progressively fewer up the

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[19] "With the favourable climatic conditions in Arctic regions, the Herring has spread to Jan Mayen, Spitzbergen, Nowaja Zemlya and Kara Sea" (Jensen, *67*:64).

[20] For details as to their regional and seasonal occurrence in the Gulf of Maine, see Bigelow and Schroeder (*15*:93).

[21] The annual "Tuna Tournament" is held at Wedgeport, Nova Scotia, not far from Yarmouth.

[22] 1946 catches, 36,103,600 for the New Brunswick shore of the Gulf; 6,080,100 for Prince Edward Island; 15,078,000 for the Magdalens; 15,525,000 for Bonaventure and Gaspé counties, Quebec.

St. Lawrence, and we find no report of them beyond Trois Pistoles, Quebec, about opposite the Saguenay River. Although the area of abundance does not extend to the northern shore of the Gulf, they are widespread there as well as in the Strait of Belle Isle; the 1946 catch for this entire coastline was only 923,700 pounds. They have been reported also for the banks in the northeastern corner of the Gulf between Newfoundland and Labrador (*125*).

They are so plentiful along the Newfoundland shores of the Gulf that they have long supported important fisheries in and off Bay of Islands and at Bonne Bay. Indeed, "it seems proven . . . that practically all the Newfoundland bays are frequented by spawning herring often in great numbers" (Thompson, *125*: 36). Thus Fortune and Placentia bays on the eastern part of the southern coast have been the sites of productive Atlantic Herring fisheries since the days of the early cod fishery; the local catch is used chiefly as cod bait.

The reported commercial catch of Atlantic Herring in 1946 for Newfoundland as a whole was only about 65 % of that for the southern part of the Gulf of St. Lawrence on the Canadian side[23]. This, taken at face value, suggests that the cold waters of eastern Newfoundland produce fewer Atlantic Herring than the waters of the south and west coasts. However this may be, they are at least moderately plentiful on the east coast of Newfoundland right up to the entrance of the Strait of Belle Isle; Jeffers not only reported them for Rahleigh but stated that they were numerous enough at Quirpon to supply the local inhabitants with winter food for their sledge dogs (*66*: 206). They have also been reported for the northern side of the Strait at Blanc Sablon (*121*: 124), and repeatedly for the Strait without specified locality.

But a review (perhaps not sufficiently searching) of the various lists of Labrador fishes has not yielded any reference to their presence anywhere to the north of the Strait, apart from Stearns' report that they are abundant "north of Blanc Sablon, growing more and more so all along the Labrador coast, the farther down which are the greatest catches" (*121*: 124).

The offshore boundary of their range follows in general the break in slope at the outer edge of the American continental shelf. Schools are occasionally seen at the surface or are picked up by trawlers here or there on Georges and Browns banks, fronting the Gulf of Maine (*15*: 95). It seems the situation is similar on the Nova Scotian Banks eastward to Banquereau and on the Newfoundland Banks, where they are often taken by otter trawlers in quantities (*125*: 36). All this has long been common knowledge among the banks fishermen. During the early years of the Georges Bank cod fishery, it was common practice to set herring drift nets for bait (*16*: 102). And it may well prove that they are much more plentiful on the banks than is now realized, for while the numbers reported (*15*: 95, for Georges Bank) have been insignificant, no serious attempt has yet been made to sample the offshore population with drift nets, midwater trawls, or bottom trawls of a kind adapted to the capture of this particular fish.

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[23] Data on Canadian catches are published annually in "Fisheries Statistics of Canada."

It has been known since Fabricius' day (*34*) that there were Atlantic Herring in western Greenland waters, in small numbers. They are now known to be widespread along the southwestern and western coasts, northward at least to 72°30′ N, though not in any great numbers if judged by the standards of northern Europe or the American coast. Their eggs have also been found in the Julianehaab district. The spawning extends through August and into September, and the presence of young fry is proof of successful local reproduction. In 1932 Hansen reported the presence of schools on the eastern coast in the neighborhood of Cape Walloe and Grittenfeldts Island (*53*: 42); he also reported the capture of a specimen near Angmagssalik. The evidence, in short, is strong that this species has expanded its range in Greenland waters during the past 30 years or so, as have other boreal sub-Arctic fishes (for details as to their occurrence in Greenland waters, see Jensen, *67*: 61–64).

Synonyms and References:[24]

Clupea harengus Linnaeus, Syst. Nat., ed. 10, 1758: 317 (diagn.); Cuvier and Valenciennes, *20*, 1847: 30, pl. 591 (descr., anat., life hist., distr., etc., includ. review of lit.); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 415 (refs., descr., Europe and N. Amer.); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1882: 265 (descr.); Goode, *et al.*, Fish. Fish. Industr. U. S., 1 (3), 1884: 549–568, pl. 204 (abund., import., distr., migr., reprod., food, capture, uses); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 421; 47 (4), 1900: fig. 18 (descr., synon.); Smith, Bull. U. S. Fish Comm. (1897), *17*, 1898: 91, (spawn., growth rate, Woods Hole, Massachusetts); Linton, Bull. U. S. Fish Comm. (1899), *19*, 1901: 437 (food, parasites); Bean, 7th Rep. Forest Comm. N. Y. (1901), 1902: 298, with fig. (econ. import., spawn., range); Bean, Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 192 (synon., refs., descr., import., abund., spawn., distr.); Fowler, Rep. N. J. St. Mus. (1905), 1906: 93, fig. (diagn., New Jersey); Smith, N. C. geol. econ. Surv., *2*, 1907: 120 (descr., range); Ehrenbaum, Eier und Larven Fisch., Nord. Plankt., 2, 1909: 361 (develop. of eggs and larvae); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31*, 1913: 741 (refs., season. abund., spawn., food, parasites, Woods Hole, Massachusetts); Cox, Contr. Canad. Biol. (1914–16), 1916: 81 (disease, Gulf of St. Lawrence, 1914); Meek, Migrations of Fish, 1916: 67–88 (genl. acct.); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 227 (diagn. in key); Lebour, J. Mar. biol. Ass. U. K., N. S. *12* (3), 1921: 459 (food of young clupeoids); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40*, 1925: 92, fig. 40 (descr., range, breed. habits, growth, size, season, movements, food, enemies, destruct. by natural causes, annu. fluct., Gulf of Maine); Jordan, Fishes, 1925: 275 (distr., abund.); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43*, 1928: 81 (refs., descr., spawn., import., rare in Chesapeake Bay); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 64, fig. (range, import., habits, size); Jordan, Manual Vert. Anim. NE U. S., 1929: 39 (diagn., range); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 41 (range, synon.); Perlmutter, 28th Rep. N. Y. Conserv. Dept., Suppl., 15 (2), 1939: 17 (spawn., eggs, young caught, Long Island, New York); Greeley, 28th Rep. N. Y. Conserv. Dept., Suppl., 15 (2), 1939: 82 (Long Island, New York); Bigelow and Schroeder, Bull. U. S. Bur. Fish., *48*, 1940: 327 (range extension; catch on Georges Bank; distr. of young); Warfell and Merriman, Bull. Bingham oceanogr. Coll., *9* (2), 1944: 51 (near New Haven, Connecticut; sizes and spawn.); Anonymous, Fish. Resources U. S., Senate Doc. No. 51, 1945: 61–62, with figs. (commerc. import., range, life hist., fluct.); Bigelow and Schroeder, Fish. Bull. (74) U.S. Fish Wildl. Serv., *53*, 1953: 88–100 (descr., life hist., Gulf of Maine).

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[24] Numerous accounts pertaining wholly or in part to this Herring have been written, for it has been a principal subject of extensive study for centuries. A complete bibliography would occupy many pages. Therefore, the references given herein are limited to the papers actually quoted (directly or indirectly), to taxonomic works of a general nature, or to faunal lists of the American coast. Many of these also contain bibliographies. Furthermore, references are given to publications containing descriptions of the species itself and of several "species" now considered synonymous with *Clupea harengus*. For additional references bearing especially on the biology of this species, see Scattergood (*114*).

Clupea elongata LeSueur, J. Acad. nat. Sci. Philad., *1* (2), 1818: 234 (orig. descr.; type local. Marblehead and Sandy Bay, Massachusetts).

Herring, Moore, Rep. U.S. Comm. Fish. (1896), *22*, 1898: 387–442 (life hist., econ. import., Passamaquoddy Bay); Huntsman, Canad. Fish. Exped. (1914–1915), 1919: 165–171 (growth of young); Lea, Canad. Fish. Exped. (1914–1915), 1919: 75–165 (age and growth, Canad. waters); Norman, Hist. Fishes, 1931: 42, 65, 80, 91, 135, 183, etc. (genl. acct.); Anonymous, Rep. U.S. Tariff Comm., (2) 69, 1933: 78, 106, 117, 143, 149–151, 157, 161, 163–165, 218 (statist. fishery products, Europ. and Amer. countries); Ford, J. Mar. biol. Ass. U.K., N.S. *19*, 1933–34: 305 (econ. of fishery, Plymouth, England; life hist. data; forecast. catch); Battle, Huntsman, Jeffers, Johnson and McNairn, J. biol. Bd. Canad., *2* (4), 1936: 401 (fatness and food of young, Passamaquoddy Bay); Marshall, Nicholls and Orr, J. Mar. biol. Ass. U.K., N.S. *22*, 1938: 245 (growth, feed., Clyde); Johnson, J. Fish. Res. Bd. Canad., *4*, 1939: 349, 392 (effects of light on movements, feed.). Leim, Tibbo, and Day, Bull. Fish. Res. Bd. Canad., 3, 1957: 1–184 (investig. e. Canada, growth, abund. populations, year-classes).

Doubtful References:

Clupea halec Mitchill, Rep. in part, Fishes of New York, 1814: 20 (orig. descr.; type local. New York; type lost; possibly a species of *Pomolobus*); Mitchill, Trans. Lit. philos. Soc. N.Y., *1*, 1815: 451 (descr.).

Clupea coerulea Mitchill, Trans. Lit. philos. Soc. N.Y., *1*, 1815: 457 (orig. descr.; type local. New York; type lost; possibly a species of *Pomolobus*).

Genus *Alosa* Link 1790

Shads

Alosa Link, Mag. Physik. Naturg., Gotha, *6* (3), 1790: 35; type species not specified; Cuvier, Règne Anim., ed. 2, *2*, 1829: 319; type species *Clupea alosa* Linnaeus, same as *Alosa* Link.

Generic Synonym:

Alausa Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 389; type species *Alausa vulgaris* Cuvier and Valenciennes equals *Clupea alosa*, apparently a variant spelling of *Alosa* Link.

Characters. BODY compressed, rather deep to elongate. BONY SCUTES rather prominent, with sharp points; the chest and abdomen with a sharp edge. CHEEK (bone below eye) notably deeper than long (Fig. 69). MOUTH large. MAXILLARY generally extending beyond middle of eye. UPPER JAW with a definite median notch. LOWER JAW largely included in upper one, its upper margin within the mouth rising gradually (Fig. 69). TEETH in jaws minute or absent (absent in American adults); none on vomer or tongue in adults. DORSAL with 16–22 rays, its last ray not produced, its origin nearer to end of snout than to base of caudal. ANAL with 18–27 rays (18–22 in American species), the last ones not enlarged. PELVIC usually with 9 rays, inserted under base of dorsal. VERTEBRAE about 52–59.

Remarks. This genus is very close to *Pomolobus*, with some of the species being difficult to separate generically. The species herein assigned to *Alosa* have a deep median notch in the upper jaw; the lower jaw shorter than the upper, with the upper margin (within mouth) not rising abruptly; the cheek deeper than long; and the adults without teeth. A combination of these characters is required to identify the species of *Alosa*.[25]

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[25] The two "wing-like plicae of skin, covered with elongate scales (*alae*)" on the base of the caudal, designated the leading diagnostic character by Borodin in his revision of the genera *Alosa* and *Pomolobus* (*18*: 175), seem unusable because too often they are indistinct on preserved specimens.

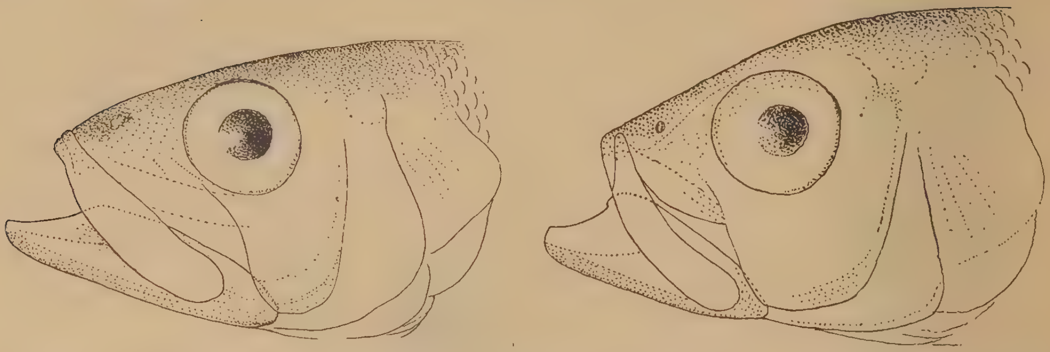

Figure 69. Heads showing shape of mandible and cheek. left, *Alosa sapidissima*, 93 mm TL, Clifton Beach, Maryland; right, *Pomolobus aestivalis*, 82 mm TL, Smith Point, Maryland. Both drawn by Louise Nash.

Range. Two species occur off Europe, another off northern Africa, and two off North America, where the recorded range extends from southeastern Newfoundland, the St. Lawrence River, Quebec, and northern Nova Scotia southward to Indian River City, Florida, and the Gulf of Mexico westward to the Mississippi River.

Key to North American Species

1 a. Lower limb of first gill arch with 59–73 rakers (26–43 in young under 125 mm). *sapidissima* (Wilson) 1811, p. 295.

1 b. Lower limb of first gill arch with 42–48 rakers in adults (27–33 in young 48–90 mm long). *alabamae* Jordan and Evermann 1896, p. 308.

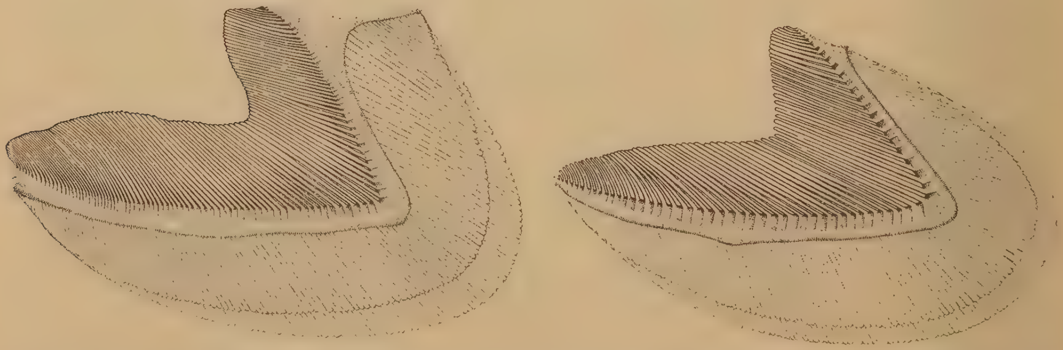

Figure 70. First branchial arch, showing numerous gill rakers: left, *Alosa sapidissima*, 550 mm TL, USNM 20969; right, *A. alabamae* (with fewer rakers), 390 mm TL, type, USNM 47689. Both drawn by Ann S. Green.

Alosa sapidissima (Wilson) 1811

American Shad, Atlantic Shad, Shad, Common Shad, White Shad

Figures 69–74

Study Material. At least 75 specimens, 35–580 mm TL, 29–475 mm SL, from St. Andrews Bay, New Brunswick; Flag Island, Eastport, and Portland, Maine; Holyoke and Woods Hole, Massachusetts; Noank, Connecticut; Long Island, and Gravesend Bay, New York; Great Egg Harbor, New Jersey; Delaware City, Delaware; many places in Chesapeake Bay and tributary streams; Avoca and Beaufort, North Carolina; and New Berlin, Florida.

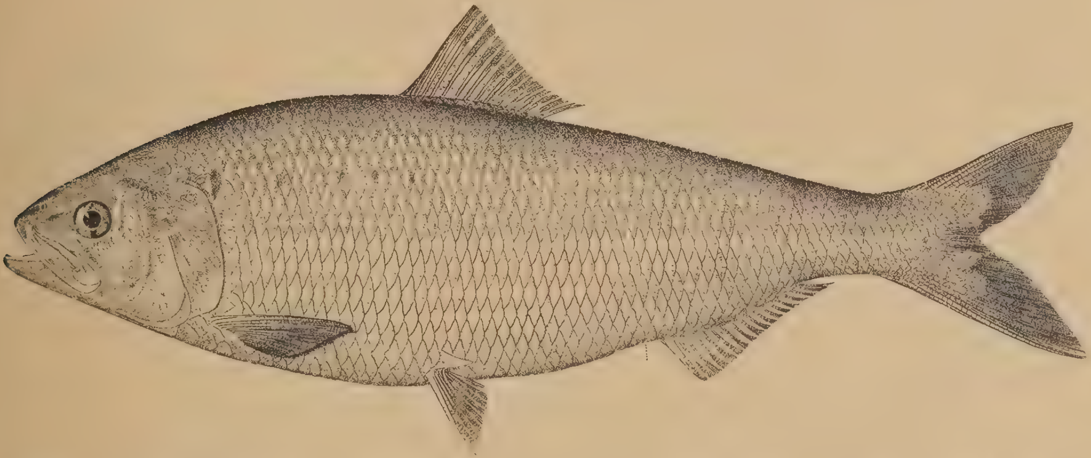

FIGURE 71. *Alosa sapidissima*, adult male, 480 mm TL, 19.13 inches, Norfolk, Virginia, USNM 25099. Drawn by H. L. Todd.

Distinctive Characters. For the features that distinguish the true shads (*Alosa*) from their close relatives, and for the difference between *sapidissima* and *alabamae*, see Key to Species, p. 294, as well as pp. 293, 304, 309, 310.

Unlike the adult with its toothless jaws and a median indentation in the upper jaw, young of 150 mm and less lack the indentation on the upper jaw and have minute teeth in the jaws. Therefore the jaw and tooth characters of the adult cannot be used in identifying the young. However, the deep narrow cheek as well as the slender mandible with its upper margin not rising abruptly to form an angle in the mouth will aid in separating young *sapidissima* from young and adult alewives of the genus *Pomolobus* (Fig. 69).

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens 29–475 mm SL.

Body: depth 30.2–36.8.
Caudal peduncle: depth 7.7–10.
Head: length 23–28.
Snout: length 4.85–7.1.

Eye: diameter 3.8–5.7.
Interorbital: width 4.55–5.95.
Maxillary: length 11–14.
Pelvic fin: length 9.9–11.9.
Pectoral fin: length 15.3–17.7.
Scales: 52–62.
Ventral scutes: 35–38.
Gill rakers: 59–73 in adults.
Fin rays: dorsal 17–20; anal 20–23; pectoral 15–17.
Vertebrae: 55–57 (4 specimens), 54–59 given in literature.

Body slender, compressed, its greatest thickness generally about half of its depth; the depth very variable, increasing with age, 2.75–4.0 in SL.

Scales moderately adherent, with crenulate membranous borders, 15 or 16 rows between base of pelvic fin and anterior dorsal rays. Ventral scutes well developed, 20–22 in front of pelvics, 14–17 behind them.

Head 3.6–4.4 in SL. Snout 3.6–4.6 in head. Eye 4.0–5.9. Interorbital 4.2–5.8. Mouth moderate, oblique; mandible included. Maxillary broad, its width about half of length of snout, with a broad supplemental bone, rounded posteriorly; reaching to middle of eye in young, generally to below posterior margin of eye in adults, 1.9–2.2 in head. Gill rakers increasing in number and proportionate length with age, those at angle shorter than snout in young but longer than snout in large specimens, 26–43 on lower limb in young 29–125 mm SL, 59–73 in specimens 300 mm SL and upward. Teeth missing in adults though present on jaws and median line of tongue in young.

Dorsal fin somewhat elevated anteriorly, its margin slightly concave, its last ray a little longer than the preceding one, its origin an eye's diameter or less in advance of pelvic fin and about equidistant between tip of snout and vertical from base of last anal ray. Caudal rather deeply forked, the lobes of nearly equal length and somewhat shorter than head. Anal low, its origin about an eye's diameter nearer to base of pelvic than to base of caudal. Pelvic near ventral edge, about equidistant between base of pectoral and origin of anal, 2.1–2.6 in head; the axillary scale equal to, or a little more than, half of length of fin. Pectoral a little higher on side than pelvic, 1.4–1.65 in head.

Color. Fresh specimens greenish to bluish with metallic luster above, gradually shading into the bright silver on sides. Dark spot on shoulder, sometimes followed by smaller spots or dots, rarely with a second parallel row of dots below the first. No dark lines along rows of scales. Fins pale to greenish, the dorsal and caudal somewhat dusky in large examples, and tips of lobes of caudal dark in some specimens. Peritoneum mostly pale to silvery.

Size. This species is the largest of the herrings. Females attain a maximum length of about 600 mm (30 in.) and a weight of 12 pounds in the Atlantic. On the Pacific coast, where the species was introduced, the maximum weight is even greater; females of 14 pounds have been reported. In the Chesapeake Bay area the average weight (and length) of females (roe shad) is probably somewhat under six pounds (about 57.5 cm; 22.75 in.), that of males (buck shad) about 3.5 pounds (about 50 cm; 20 in.).

Development and Growth. The eggs, about 3.5 mm in diameter after they are impregnated, are demersal, but they are only slightly heavier than the water in which they are deposited. As they are not adhesive, they drop loosely and singly to the bottom. According to Ryder they hatch in 52 hours at an average temperature of 57.2° F, and in less than 36 hours at an average of 74° F (*112*: 796). However, a longer incubation period was reported by Leim (*81*: 31), who said that eggs held under artificial conditions hatched in 12–15 days at 12° C (53.6° F) and in 6–8 days at 17° C (62.6° F).

The newly hatched fish, transparent and extremely slender, are about 9–10 mm long. The yolk is absorbed in four or five days at a water temperature of 62.5° F and in about seven days at 53.5° F; the fish have then attained a length of about 12–15.5 mm (*81*: 33). In some preserved specimens that show the yolk almost absorbed, the depth is only about 0.05 of the length, the large dark eyes protrude prominently, the dorsal fin fold is somewhat developed, and the alimentary canal is discernible, ending under the beginning of the posterior sixth of the body. During development, the vent moves forward as in other Clupeidae. The fins are fully developed in 21–28 days at a length of about 20 mm, when metamorphosis is nearly complete (*16*: 118). For a more detailed account of the development of the larvae, see Leim (*81*: 31–43).

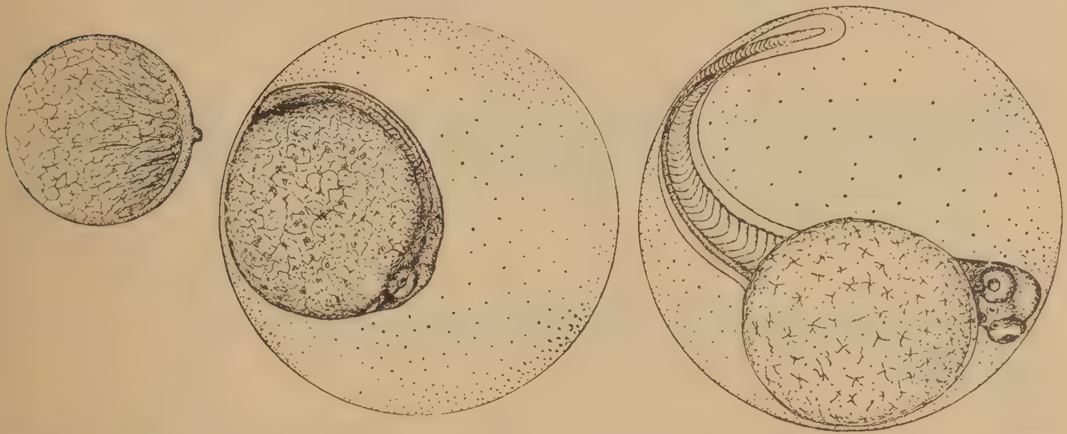

FIGURE 72. *Alosa sapidissima* egg development. LEFT to RIGHT: newly laid egg; embryo in natural position within enveloping membrane of egg (photograph); egg with embryo nearly ready to hatch. After Leach.

The young remain more slender than the adults until they are nearly grown fish, but even among sexually mature fish there is great variation in depth, seemingly not related to sex and only partly related to spawning conditions. In 25 young, 35–125 mm long, the depth varied between 26.5–30 % of SL, and in a lot of 12, 460–505 mm long, the depth was 32–48 % of SL.

A gradual increase in the number of gill rakers, as already indicated, also takes place with age and growth. For example, the number on the lower limb of the first arch varied as follows: in 18 young 35 to 65 mm long, 26 to 31; in 21 examples

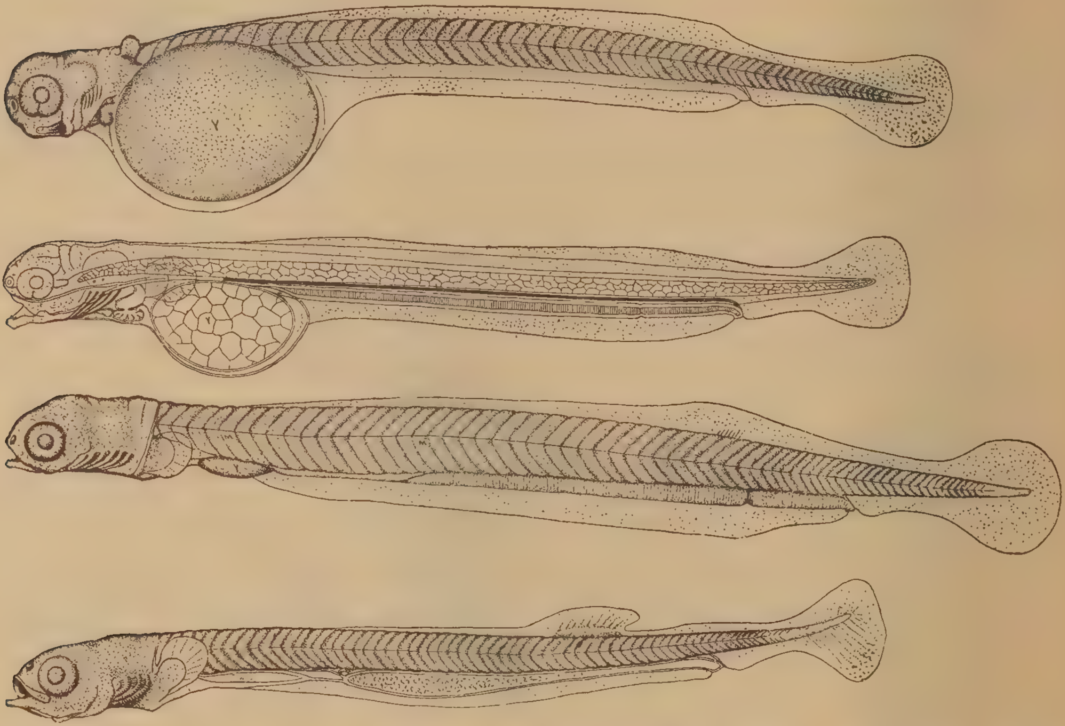

FIGURE 73. *Alosa sapidissima,* larval development. TOP, immediately after hatching; UPPER CENTER, third day after hatching; LOWER CENTER, five days after hatching; BOTTOM, 17 days after hatching. After Leach.

70 to 125 mm, 34 to 43; in 16 immature fish 190 to 270 mm, 48 to 62; and in 32 sexually mature examples 465 to 580 mm, 59 to 73.

The young grow rapidly during their first summer while in fresh water. The total lengths of 769 young taken in the Chesapeake Bay area—mostly from the Potomac River (in 1912)—ranged between 20–69 mm during June, 30–74 mm during July, 45–79 mm during August, 50–95 mm during September, 45–99 mm during October, and 60–119 mm during November (*59*: 98).

Larger young of 150, 175, and even 225 mm, at an age of seven months, have been reported. Such fish, in at least one instance, are known to have lived under specially favorable conditions in a pond well supplied with food (at Washington). Furthermore, according to Bean: "Nets set off shore in Gravesend bay [New York] in the fall frequently inclose large quantities of young shad, sometimes a ton and a half at one time, during the migration seaward ... The fish are usually about 6 to 8 inches long" (*8*: 208). One may question whether fish of such a large size, taken in such large quantities, were only six to seven months old. That the young grow faster north of Chesapeake Bay seems unlikely in the light of a statement by Bigelow and Welsh (*16*: 118) concerning this Shad in the Gulf of Maine: "The young shad remain in the rivers until fall when, at a length of $1^{1}/_{2}$ to $4^{1}/_{2}$ inches (37 to 112 mm) and resembling their parents in appearance, they move down to salt water." This range in length is close to that of fish of the same age from Chesapeake Bay and does not indicate more rapid growth in the more northern part of the range. However, Bigelow and Welsh added: "In the rivers of Maine the fry may be as long as 5 to 7 inches (125 to 175 mm) by the first week of November." Included in Hildebrand and Schroeder's data there were three specimens from the November collection that ranged somewhere between 145 and 244 mm in length (59); these fish were so much larger than the other 137 specimens taken in the same month that one is led again to suspect that they may have belonged to the one-year class.

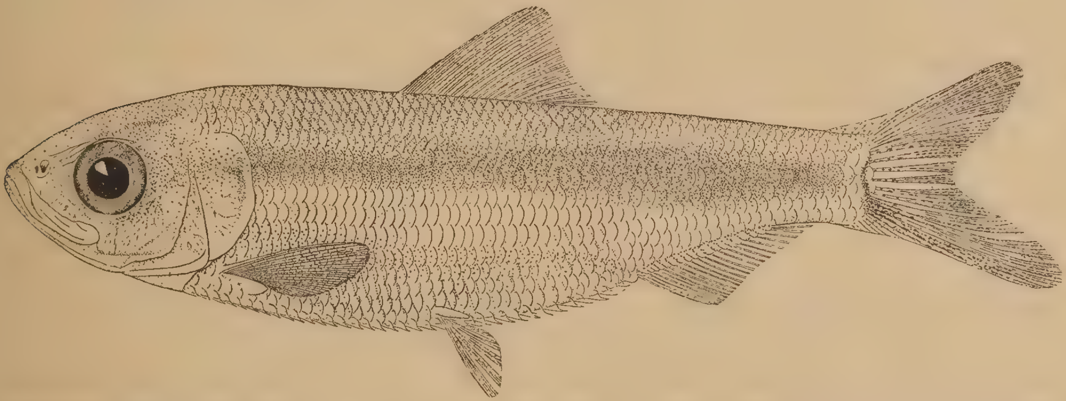

FIGURE 74. *Alosa sapidissima*, young, 47 mm TL, 1.88 inches, Beaufort, North Carolina. Drawn by Louella E. Cable.

The growth rate after the young have entered salt water is not well known because of the lack of specimens available for examination. Hildebrand and Schroeder listed 22 specimens that were spending their first winter in the deeper places of Chesapeake Bay instead of continuing their migration to sea (59: 98). Eight of these, taken in January, ranged between 95–124 mm and averaged 108 mm, 3 taken in February were 95, 105, and 135 mm long, 10 taken in March ranged between 105–159 mm and averaged 142 mm, and 2 taken in May were 145 and 154 mm long. Specimens of a somewhat similar size were dredged during the winter in the estuary of Newport River, Beaufort, North Carolina; 18 specimens caught in January ranged between 73–140 mm and averaged 117 mm; 14 caught in February were 100–160 mm and averaged 121 mm; and 3 caught in March were 84, 102, and 120 mm long.

Using mostly specimens from the Connecticut River, Borodin[26] (*17*: 183) determined the age of older fish from the annuli and transverse grooves on the scales, a method confirmed as practicable in Barney's study of otoliths (*5*: 168). Borodin provided a list of 10 size groups to which he assigned ages as follows: Group 1 — 58 to 113 mm long, 26 specimens from the river, all less than a year old; Group 2 — 145 to 180 mm long, 4 from salt water, in their second year; Group 3 — 210 to 290 mm, 7 from salt water, in their third year; Group 4 — 300 to 350 mm, 10 young males entering the river, in their fourth year; Group 5 — 360 to 390 mm, 22 young males entering the river, in their fifth year; Group 6 — 400 to 430 mm, 13 males and 9 females, in their fifth, sixth, and seventh years; Group 7 — 440 to 480 mm, 34 males and 9 females, in their sixth, seventh, and eighth years; Group 8 — 490 to 520 mm, 28 males and 13 females, in their seventh, eighth, and ninth years; Group 9 — 530 to 570 mm, 6 males and 43 females, in their seventh, eighth, ninth, and tenth years; and Group 10 — 580 to 660 mm long, 1 male and 23 females, in their eighth, ninth, tenth, and eleventh years.

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[26] Borodin, in determining the age of Shad from the scales, used the transverse grooves in addition to the annuli, having discovered that two complete transverse grooves are formed each year. Barney determined their age from the "limy deposits" in the otoliths, which form annual rings; he found that these annuli correspond to the annuli and crossgrooves on the scales used by Borodin.

Young fish from the Bay of Fundy reach a length of 41–45 mm in nine to ten weeks (*81*: 74–84). Leim's calculations, based on scale readings of adult fish, in general indicate a rather faster rate of growth for his fish than for those of Borodin.

Some of the males, according to Borodin, enter the Connecticut River from the sea when they are 300–350 mm long and in their fourth year, as shown in the preceding data. Although the author did not say so, these males undoubtedly were sexually mature, as migration to the rivers seems to be carried out solely for the purpose of spawning. The smallest females that returned to the Connecticut to spawn, according to the same author, were between 400 and 430 mm long and in their fifth, sixth, and seventh years. Therefore, the males seem to become sexually mature at an earlier age than the females. On the other hand, females may reach a greater age; among the older fish examined by Borodin, determined by him to be in their seventh, eighth, ninth, tenth, and eleventh years, there were only 7 males compared to 86 females. Concerning the Bay of Fundy fish, Leim said: "Most of the shad present on the spawning grounds were five years old or over and eight or nine years seems to have been the maximum age represented. Fish under four years of age apparently do not spawn at all" (*81*). The discrepancy in the rate of growth and the age of spawning fish, as determined by Borodin and by Leim, may have resulted from a difference in the interpretation of the scale markings, or from a difference in the behavior of two rather widely separated races that may respond differently to the climatic or general environmental conditions in which they live.

Reproduction. The average number of eggs produced by a single fish varies between 25,000–30,000 (*119*: 127). In the *Manual of Fish Culture* (*2*: 125) it is stated that the average number is not more than 30,000 but that a single fish has been known to yield between 60,000 and 115,000 eggs. In 1885, one from the Delaware River yielded 156,000. In this species, as among others, large fish as a rule produce many more eggs than small ones.

If all of the large number of eggs produced by a female hatched and reached maturity, the progeny would be exceedingly great. However, it is quite certain that normally only a small proportion of the eggs produces fish that live to maturity. The most critical time in the life cycle apparently comes when the larvae have absorbed the yolk and must find their own food. If food is found and if other conditions are favorable for survival, then the spawning season is a successful one. The success or failure of a spawning season in a river is usually evident from the size of subsequent catches when the fish hatched in a given year return later to spawn in the same stream. The comparatively large fluctuations in catches over a period of years no doubt result in large part from the measure of success of the particular spawnings from which the fish composing the catches were derived.

Spawning and Migrations. American Shad spawn in fresh water. Some spawn as soon as they arrive from the sea while others do not spawn until they reach the upper tributaries of rivers. Virtually all spawning, in this species as in many others, takes place in the evening between five and ten o'clock. While spawning, the fish are paired, swimming close together side by side. Since no nests are made, the eggs fall loosely in the water, and doubtless many are smothered when they fall on muddy bottom. An individual returns to spawn year after year.

The water temperature governs the date when mature American Shad approach the mouths of the rivers to spawn, about 50–55° being required. Accordingly, they appear off the Florida coast (St. Johns River) in November, to remain until March, in the sounds along the Carolina coast in February and March, in the Chesapeake Bay area in March and April, and farther north in May and June. But the precise date of arrival at any particular locality along the coast may vary by a couple of weeks from year to year, depending on the variation from year to year in the vernal warming of the water.

In large rivers, they run far upstream if their passage is not blocked. Thus they still run up 375 miles (or did recently) in the St. Johns River in Florida, 300 miles in the Altamaha in Georgia, about 200 miles in the St. John in New Brunswick, and at least 200 miles in the St. Lawrence (*122*: 11; *127*: 129, 130). American Shad ascending the estuary of the St. Lawrence may travel as much as 25–50 miles in 24 hours (*127*: 129).

The spent fish, very thin after spawning, begin their return journey to the sea immediately afterward; i. e. in March to May in the southern part of the range and in June to August in the northern part. But the young fry (product of that season's spawning) remain in the parent stream until autumn, when the temperature falls to 60° or lower. In the Chesapeake Bay region, their migration out into salt water takes place principally in October and November; but it is not until late November or December that all of them are in salt water.

Southward from Cape Cod the spent fish vanish upon re-entering salt water. While a few young fry in the Chesapeake Bay area spend their first winter in the deeper parts of the Bay, those from the Hudson may linger nearby for an entire year, for catches of 6- to 8-inch fish in Gravesend Bay in autumn have been reported (*8*: 208). The larger sizes of immature fish vanish as completely from the southern part of the coast as do the spent fish, until they reappear there for their first spawning.

Spent fish up to ten pounds and averaging about five pounds have been reported as taken in the Gulf of Maine, and schools of them have been seined from time to time in summer and autumn, even in December, at various places along the Maine coast, where they have been the object of a frozen-fish industry in some years. Immature fish (0.5–2.5 pounds) sometimes congregate also along the Maine coast and are more or less common in the Massachusetts Bay region.

Clearly these Gulf of Maine fish are far too numerous to be derived only from the streams of the Bay of Fundy, as was formerly considered likely (*16*: 116). Recently, extensive tagging experiments (*15*: 111, ftn. 18–20; *124*) have shown that, while some of them come from as far south as the Altamaha River, Georgia, others come from as far north as the St. Lawrence estuary, both of these contingents to fatten in the Gulf. By the end of December, however, they have vanished, not to reappear anywhere on the coast until the onset of the next spawning season, when the maturing fish return to the rivers of their native watersheds.

Like salmon and alewives, American Shad spend most of their life in the sea and make most of their growth there, but where they winter remains to be discovered. While in the sea, Shad are schooling fish, often in the thousands, and they never reenter fresh water until they return to spawn, although they may appear in brackish estuaries. They have been taken 25–90 miles out off southern New England, 110 miles out on Georges Bank, 40–50 miles out off the coast of Maine, and 50–60 miles off eastern Nova Scotia, and as deep as 50–68 fms.

Food. The diet of 14 young fish, 43–60 mm long, from fresh water of the Potomac River, consisted chiefly of adult and larval insects and ostracods, and in one instance a small fish (*59*: 95). Larger juveniles, 100–150 mm long, caught in Chesapeake Bay, presumably while en route to the sea, had fed mostly on *Mysis*, although one stomach contained fragments of a small fish, and another fragments of plant tissue.

Working with young specimens from the Shubenacadie River, tributary to the Bay of Fundy and its estuary, Leim found that the first food taken by larvae 11 mm long consisted of midge larvae (Chironomidae), while the somewhat larger larvae had fed principally on mature and immature copepods (*81*: 16). In fact, these organisms constituted the chief food of the young up to the time of transformation, with the relative abundance of these forms in a particular locality determining which food predominated. Dr. Leim's data show also that young adults taken in the same general vicinity continued to subsist principally on these same organisms. Other foods ingested consisted of ostracods, amphipods, insects, and fish.

Little or no food has been found in the stomachs of those caught while in fresh water en route to their spawning grounds, indicating that these fish, like salmon, do not ordinarily feed then. However, there are some records showing that adults occasionally do take food while in fresh water, at least late during the spawning season. They will often take a live minnow or an artificial fly when working upstream on their spawning run.

Many kinds of food have been found in the stomachs of those taken in salt water in estuaries and bays north of Cape Cod. But southward, examples are rarely obtainable in salt water, except during the migration to and from the spawning grounds. Therefore it is of interest that an adult female, caught in Chesapeake Bay in December, was gorged with parts of plants, among which were fragments of a mollusk shell. It has been reported also that adults taken in the vicinity of Savannah, Georgia, had fed on plants. Others caught near Fort Lee, New Jersey, had fed liberally on young shrimp, and still others, taken in Delaware Bay, had eaten small fish.

From an examination of about 350 stomachs of both mature and immature fish caught in the salt water of Scotsman Bay, Bay of Fundy, Leim found that, while copepods constituted the chief food of the smaller ones, as in fresh water, these crustaceans were unimportant in fish 400 mm and more in length (*81*: 68). Mysids, which were sparingly eaten by small fish, were the chief food of adult fish. In general, about 90 % of the specimens of all sizes from that area had eaten copepods and mysids, with ostracods, amphipods, isopods, decapod larvae, insects, mollusks, algae, fish eggs, and fish making up the remainder. After examining many stomachs of specimens taken in the Bay of Fundy, Willey also concluded that the chief foods consisted of copepods and mysids, to which he added shrimp and larval stages of barnacles (*133*: 313–320). Stomachs of fish from the Gulf of Maine have been found full of copepods (chiefly *Calanus*). American Shad also feed greedily on pelagic euphausiid shrimps.

Enemies. No doubt the larger predatory fishes are the principal enemies of the young while the latter are in the rivers. Although no records at hand show definitely that this is so, it can scarcely be otherwise, for the young are not rapid swimmers and do not ordinarily seek protection among plants or other cover. Furthermore, they are small enough, at least during the early part of summer, to be swallowed by bass and other carnivorous fishes only an inch or two long. Water birds, turtles, and water snakes no doubt feed on them too. The toll taken by predatory fishes while the young are en route to the sea may not be very great, for this migration takes place in the fall when many marine fishes (at least in Chesapeake Bay) have left the shallow waters. At sea they doubtless fall prey to all the larger predaceous fishes, and perhaps to finback whales as well.

The chief enemy of the adults is man, who has not only depleted the stock in many rivers through overfishing but has cut them off from spawning areas through the construction of barriers and by polluting the waters with deleterious wastes.

Parasites. The parasites of *A. sapidissima* have been made known principally through several papers by Edwin Linton and by Charles B. Wilson, based mostly on specimens obtained from fish caught in the vicinity of Woods Hole, Massachusetts. The findings were summarized by Sumner, *et al.* (*123*: 742) as follows: "Acanthocephala (Linton) *Echinorhynchus acus.* Nematodes (Linton) — *Ascaris adunca*, *Ascaris* sp. (immature). Copepods (C. B. Wilson) — *Caligus rapax.*" To this list was added the copepod *Lernaeenicus radiatus* (*135*: 59). Working with both young and adults from the Shubenacadie River and Scotsman Bay, Leim found no external parasites and only three internal ones, namely "distomes, nematodes, and Acanthocephali" (*81*: 74). It is not stated whether any of these parasites were considered seriously detrimental to the host.

Relationships. There are two well-marked species of this genus in Europe, *A. alosa* and *A. finta*, both of which have the deep cheek and notched upper jaw as in American species. However, *A. alosa* has smaller scales (72–80 lateral series) and more numerous gill rakers (72–86 on lower limb in adults) than the American species. *A. finta*, while agreeing with the American species as to scales, has only about 24–32 gill rakers on the lower limb, in grown examples.

The two American species recognized here, namely *A. sapidissima* and *A. alabamae*, differ principally in the number of gill rakers; mature examples of *sapidissima* have 59–73 on the lower limb whereas specimens of *alabamae* of similar size have only 41–48. The relationship of these species is discussed further in the account of *alabamae* (pp. 309, 310).

Variations. The specimens examined, from various localities within the range (p. 295) and used in preparing the *Description*, do not differ specifically or subspecifically. However, racial differences have been recognized. Vladykov and Wallace have found slight average differences in the number of vertebrae, pectoral rays, and ventral scutes between examples from the Bay of Fundy, Delaware Bay, and Chesapeake Bay; these they regarded as different "populations" (*130*: 52–66). Investigators of the U. S. Fish and Wildlife Service, in a special study of *A. sapidissima*, found that virtually every important river system within the range of this fish is inhabited by a different race (unpublished data).

Commercial Importance. This species has been an important foodfish throughout its entire range since the earliest settlers arrived, and no doubt these fish were taken by the Indians long before. Unfortunately, pollution, overfishing, and dams constructed across the streams (preventing the fish from reaching their spawning grounds) have caused partial and sometimes serious depletion, or even virtual extermination. So many streams have been dammed, particularly in New England, that, in the words of Bigelow and Welsh: "the local stock of shad has diminished until now the Gulf of Maine stock is but a shadow of its former abundance . . ." (*16*: 114). The great decline in abundance in New England is evident from the published statistics of the former United States Fish Commission, U. S. Bureau of Fisheries, and the present U. S. Fish and Wildlife Service;[27] the annual New England catch between 1889–1908 seems to have been well above 1.25 million pounds, by 1919 it had fallen somewhat below a million pounds, and between 1924–1940 it has fluctuated around a half million pounds.

The situation with respect to the American Shad fishery in the Hudson is much more encouraging, although depletion occurred in that river also; statistics from the sources previously mentioned show that the catch in that river declined from 3.75 million pounds in 1901 to only 40,000 pounds in 1916 and to 43,000 in 1917; thereafter, between 1918–1935, the catch varied from 94,000 pounds (1924) to 847,000 pounds (1935); and in 1936–1941 it varied from 2,467,000 (1938) to 3,270,700 (1939). Although the catch in 1959 was only 1,171,212 pounds, very definite recovery has been indicated. According to investigators of the U. S. Fish and Wildlife Service, this recovery is ascribed partially to the elimination of pollution and partially to the great decrease in fishing effort at the time when depletion made it unprofitable to fish. The curtailment in fishing permitted the depleted population to reach the spawning grounds, to return to the sea, and to spawn again and again. Ultimately this resulted in the rehabilitation of the American Shad in this river system. It is decidely encouraging to have evidence that a depleted fishery can be restored.

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[27] No adjustment for the differences in the number of persons employed, the type and number of vessels, and the different types of gear used from year to year has been made in the statistics given here and elsewhere. However, it is highly probable that the "fishing effort" for 1000 pounds of fish, for example, has increased.

The American Shad fishery in the Potomac, though it has fluctuated greatly, has also undergone a general decline in recent years, without evident recovery. The catches in 1896 and 1901 were above 2.5 million pounds whereas in 1909 and 1915 they were only three-quarters of a million pounds. Then from 1919 to 1923 they ranged above a million pounds, reaching the impressive totals of somewhat more than two million pounds in 1919 and over three million pounds in 1922; the latter is the greatest catch on record. In 1924 the catch dropped to a little over half a million pounds, and since then it exceeded a million pounds only in 1926, 1928, 1929, 1931, and 1933; in fact, the catch exceeded two million pounds in 1928, 1931, and 1932. However, between 1934–1941 it has fluctuated only from 631,000 pounds in 1935 to 322,800 pounds in 1940, the smallest catch recorded. Although great fluctuations in the catches, and no doubt in abundance, have occurred in the Potomac River since 1896, a definite decline was not indicated by the statistics until 1934. Thereafter, a general decrease in the catches has reached alarming proportions. In 1959 the catch was only 188,000 pounds.

A decline similar to that in the Potomac River has taken place in the entire Chesapeake Bay area, where, exclusive of annual fluctuations in the catch, the general trend has been downward since 1930. According to statistics, this same situation also applies to the South Atlantic states, and perhaps to a somewhat smaller extent to the fisheries of the Middle Atlantic states.

The over-all yield of late has ranged between catches of 8,222,000 and 14,700,000 pounds for the United States (1940, 1945, 1950–1953), and between 1,545,000 and 2,444,000 pounds for Canada (1940, 1945, 1950–1952). The American Shad thus remains very important economically, yielding the fishermen an annual return of over a million dollars.

Formerly, when they were abundant, the market for them more limited, transportation slower, and refrigeration virtually unknown, a considerable portion of the catch was salted. However, now nearly all of it is marketed in the fresh state. Johnson has stated, "During recent years the outstanding problem of wholesale dealers, insofar as shad are concerned usually has been one of obtaining adequate supplies rather than of disposing of the catch" (*68*: 15). In fact, the demand on the Atlantic coast has been so great that the supply is augmented annually by shipments from the Pacific coast. The chief markets on the Atlantic coast are New York, Philadelphia, Baltimore, and Washington.

Shad are caught principally with pound nets, gill nets, and seines. Small quantities are taken with fyke nets, otter trawls, purse seines, traps, and dip nets.

Introductions. In the late 1800's, many introductions of the fry were attempted by the former U. S. Fish Commission and U. S. Bureau of Fisheries, but all failed; large shipments were liberated in the streams tributary to the Gulf of Mexico, in Great Salt Lake, Utah Lake, and Bear Lake, Utah, and in the Colorado River at the Needles, Arizona.

In the 1870's, the New York State Fish Commission introduced numerous fry in streams tributary to Lake Ontario and in some of the smaller lakes connected to it. According to Smith (*118*: 193), 658,000 fry were introduced, and "the appearance of adult shad promptly followed the introduction of young fish in the Genesee River, and from that time on for a number of years the indications pointed to the probable successful acclimatization of the species." These fish distributed themselves over the entire lake and were taken at irregular intervals from 1875 to about 1885; but few, if any, were seen after 1890. Hubbs and Lagler reported: "In the Great Lakes rare, and confined to the Lake Ontario Basin" (*62*: 27).

Remarkable success has resulted from stocking waters of the Pacific coast north of Monterey, California. The first fry, about 12,000, were planted in 1871 in the Sacramento River by the California Fish Commission, and additional shipments were sent there by the United States Fish Commission between 1873–1880. On the northern part of the Pacific coast, fry were introduced in the Willamette, Snake, and Columbia rivers in 1885 and 1886. From these plantings the species has spread from California to Alaska, and it has become important commercially from San Francisco northward; the catch during recent years generally has exceeded two million pounds.[28]

Artificial Propagation. This species received the attention of fish culturists as early as 1848 when eggs were taken artificially and hatched. However, it was not until 1867 that a really successful apparatus was perfected. This contrivance was known as the "Seth Green box," a floating box modified after one used for hatching salmon eggs. However, when used in tidal waters it was subject to accidents. Thereafter various devices were brought forward in rapid succession, and finally (in 1882) the "universal jar" or "McDonald jar," a modification of the "Chase jar" used for hatching whitefish eggs, was adopted by the U. S. Fish Commission and is still in use. Many millions of fry, or newly hatched larvae, have been liberated in the streams along the Atlantic coast.

Range. The regular range of the American Shad extends from the lower St. Lawrence River and Nova Scotian Banks as far south as Indian River City, Florida. The most northerly record is for one taken in Bulls Bay near St. John's, Newfoundland (*1*: 125). On the Pacific coast it now ranges from about San Pedro, California, to southeastern Alaska (*131*: 221).

Synonyms and References:

Clupea sapidissima Wilson *in* Rees's New Cyclopedia, *9*, *ca.* 1811: no pagination (orig. descr.; no local.; probably Philadelphia, Pennsylvania); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1882: 267 (descr., range);

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[28] For further details concerning their artificial propagation and distribution, see *A Manual of Fish Culture* (*2*: 133–158).

Smith, Bull. U. S. Fish. Comm. (1890), *10*, 1892: 193, pl. 30 (deposited in small lakes and streams connected to Lake Ontario); Cheney, Rep. Forest Comm. N. Y. (1885), 1896: 125–134, color pl. (commerc. import., statist., artif. culture, local spawn., migr.).

Clupea alosa Mitchill (not of Linnaeus), Trans. Lit. philos. Soc. N. Y., *1*, 1815: 449 (descr., habits, size).

Alosa preastabilis DeKay, New York Fauna, Pt. 4, Fishes, 1842: 255, pl. 15, fig. 41 (orig. descr.; type local. New York; cf. European shad).

Alausa sapidissima Gill, Proc. Acad. nat. Sci. Philad., 1861: 54.

Alosa sapidissima Uhler and Lugger *in* Rep. Comm. Fish. Md., 1876: 157; 1876: 133 (descr., synon., food qualities, Maryland); Ryder, Rep. U. S. Comm. Fish. (1881), 1884: 795 (temp. effects on incub. of eggs); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 427; 47 (4), 1900: fig. 191 (descr., range, synon.); Anonymous, Rep. U. S. Comm. Fish. (1897), 1898: 133, pls. 36–39 (artif. propag. and develop.); Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 305, fig. (synon., range, occur., size, food of young in rivers, spawn.); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 204 (synon., refs., decline due to obstructions, food, migr., growth); Fowler, Rep. N. J. St. Mus. (1905), 1906: 99 (descr., import. as food); Smith, N. C. geol. econ. Surv., *2*, 1907: 125, pl. 5 in color (synon., descr., range, foodfish; rel. size of male and female, migr., statist., etc.); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7*, 1908: 39 (refs., New England); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31* (2), 1913: 742 (refs., Woods Hole, Massachusetts, spawn., parasites); Regan, Ann. Mag. nat. Hist., (8) *18*, 1916: 8 (diagn.); Wilson, Proc. U. S. nat. Mus., *53*, 1917: 59 (parasites); Leim, Contr. Canad. Biol., N. S. *2* (1), 1924: 163–284 (life hist., bibliog.); Barney, Trans. Amer. Fish. Soc., *54*, 1924: 168, figs. 1–4 (age from otoliths); Borodin, Trans. Amer. Fish. Soc., *54*, 1924: 178 (age from scales); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40* (1), 1925: 113, fig. 46 (descr., size, range, Gulf of Maine, migr., food, develop., etc.); Jordan, Fishes, 1925: 276 (relation., quality as food, spawn.); Nichols and Breder, Zoologica, N. Y., *9* (1), 1927: 40, fig. (distr., New York and New England, food, life hist., size); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), 43 (1), 1928: 93, fig. 53 (descr., growth of young, food, migr., artif. propag., distr., commerc. import., marketing, size, range); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 66, fig. (abund., decline, migr., food, spawn.); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 40 (diagn., range); Truitt, Bean, and Fowler, Bull. Md. Conserv. Dep., 3, 1929: 50, fig. 16 (descr., Maryland); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 42 (range, synon.); Walford, Fish. Bull., Sacramento, 28, 1931: 48 (diagn., distr. Pacific coast, commerc. import.); Greeley and Bishop, 21st Rep. N. Y. Conserv. Dep. (1931), Suppl., 6, 1932: 78 (rare, Oswegatchie and Black R. systems); Greeley and Bishop, 22nd Rep. N. Y. Conserv. Dep. (1932), Suppl., 7, 1933: 91 (extinct, upper Hudson); Greeley, 24th Rep. N. Y. Conserv. Dep. (1934), Suppl., 9, 1935: 90 (Hudson R.); Greeley, 25th Rep. N. Y. Conserv. Dep. (1935), Suppl., 10, 1936: 78 (Delaware R. within New York); Greeley, 26th Rep. N. Y. Conserv. Dep. (1936), Suppl., 11, 1937: 91, pl. 3 in color (abund. Hudson R., spawn.); Vladykov and Wallace, Trans. Amer. Fish. Soc. (1937), *67* (2), 1938: 52–66; also Contr. 17, Chesapeake Biol. Lab. (commerc. import., Chesapeake Bay; var. in populations); Greeley, 28th Rep. N. Y. Conserv. Dep. (1938), Suppl., 15 (1), 1939: 39; 15 (2), 1939: 82 (fresh water, Long Island, New York); Greeley, 29th Rep. N. Y. Conserv. Dep. (1939), Suppl., 16, 1940: 68 (rare, Lake Ontario); Welander, Copeia, 1940: 221 (introd., distr. Pacific coast); Hubbs and Lagler, Bull. Cranbrook Inst. Sci., 18, 1941: 27 (range); Fowler, Monogr. Acad. nat. Sci. Philad., 7, 1945: 45 (synon., refs.); Anonymous, Fish. Resourc. U. S., Senate Doc. No. 51, 1945: iii, 67–68, fig. (migr., fish. management; decline, causes and remedies; range); Warfel and Olsen, Copeia, 1947: 177–183 (var. in no. of vert. and signif.); Bigelow and Schroeder, Fish. Bull. (74) U. S. Fish Wildl. Serv., 53, 1953: 108–112 (descr., life hist., Gulf of Maine).

Shad, Clark, Rep. U. S. Comm. Fish. (1881), 1884: 783 (amount of water needed to keep eggs and young alive); Rice, Rep. U. S. Comm. Fish. (1881), 1884: 787 (retard. develop. of eggs); Willey, Contr. Canad. Biol., N. S. *1* (16), 1923: 313–320 (food); Johnson, Invest. Rep. U. S. Bur. Fish., *2* (38), 1938: 1–42, figs. 1–9 (nat. hist., sources of fishery, capture, wholesale trade, consump. in homes and public eating places, nutr. value, recipes, etc.); Hollis, Science, *108* (2804), 1948: 332 (tagging young; return of mature fish to place of hatch.).

Doubtful References:

Clupea indigena Mitchill, Rep. in part on Fishes of New York, 1814: 22 (orig. descr.; type local. presumably New York; type lost); Mitchill, Trans. lit. philos. Soc. N. Y., *1*, 1815: 454 (descr. inadequate for ident.).

Negative Reference:
Clupea sapidissima Jordan and Gilbert (not of Wilson), Proc. U. S. nat. Mus., 5, 1882: 247 (proportions and counts, showing specimens were *A. alabamae*, not recognized until 1896; Pensacola, Florida).

Alosa alabamae Jordan and Evermann 1896

Alabama Shad, Gulf Shad, Ohio Shad

Figures 70, 75

Study Material. A total of 23 specimens, 175–505 mm TL, 145–395 mm SL, from the Choctawhatchee River, Pensacola, Florida (including two cotypes of *A. alabamae*); tributary of the Flint River, Georgia; Black Warrior River, Tuscaloosa, Alabama (male and female types); Coosa River, and the Alabama River, tributary of the Tombigbee River, Alabama; Washita River, near Hot Springs, Arkansas; Ohio River at the falls, Louisville, Kentucky (including type and several cotypes of *A. ohiensis*); and Fairport, Iowa.

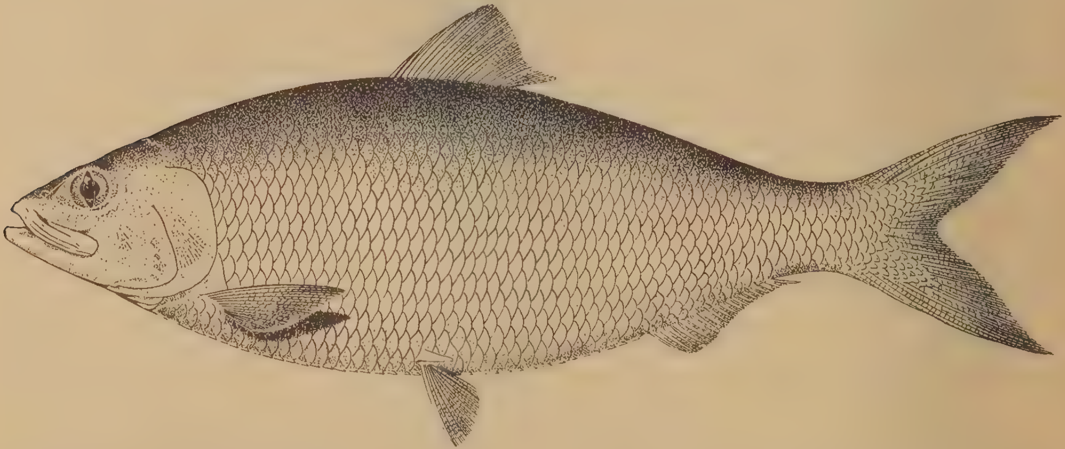

FIGURE 75. *Alosa alabamae*, 380 mm TL, 15 inches, Black Warrior River, Tuscaloosa, Alabama, type, USNM 47689. Drawn by A. H. Baldwin.

Distinctive Characters. See Key to Species, p. 294, and pp. 304, 309, 310.

Description. Proportional dimensions in per cent of standard length, and counts, based on the 23 study specimens, 145–395 mm SL.

Body: depth 25.5–36.
Caudal peduncle: depth 8.0–9.0.
Head: length 23.5–26.5.
Snout: length 5.5–6.9.
Eye: diameter 4.2–6.5.
Interorbital: width 4.5–6.0.

Maxillary: length 11–13.5.
Pelvic fin: length 10–11.5.
Pectoral fin: length 15.3–17.5.

Scales: *ca.* 55–60, often lost in preserved specimens.

Ventral scutes: 35–38.
Gill rakers: 42–48 in adults.
Fin rays: dorsal 16–20, usually 17–19; anal 19–22; pectoral 15–18, usually 16 or 17.
Vertebrae: 55 (1 specimen).

BODY shaped as in *A. sapidissima*, the depth in general increasing with age and growth, 2.8–3.9 in SL in adults. HEAD 3.7–4.25 in SL. SNOUT 3.8–4.4 in head. EYE 4.2–6.5. INTERORBITAL 4.1–6.0. MAXILLARY 1.95–2.15. SCALES only moderately adherent, about 15 or 16 rows between base of pelvic and anterior rays of dorsal fin. PELVIC fin 2.2–2.5 in head. PECTORAL fin 1.4–1.5.

A. alabamae differs from *A. sapidissima* in only the few respects shown in the following comparison:

A. sapidissima	*A. alabamae*
Gill rakers close-set, those at angle of first arch longer than snout, 59–73 on lower limb in adults 300 mm and upward.	Gill rakers less crowded, those at angle of first arch about as long as snout, 42–48 on lower limb in adults 300 mm and upward in length.
Surface of cheek and opercular bones glossy, generally without conspicuous mucous pores and canals.	Surface of cheek and opercular bones not glossy, covered with conspicuous mucous pores and canals.
Axillary scale of pelvic fin generally only a little more than half of length of fin.	Axillary scale of pelvic fin generally about 75 % of length of fin.

Size. The Alabama Shad seems to run smaller in size than the American shad; the largest female seen was 510 mm (20.4 in.) and the largest male 435 mm (17.4 in.) long, both from the Ohio River at Louisville, Kentucky.

Development. Apparently the eggs and young have not been described. Ten small specimens, 48–90 mm TL, 36–73 mm SL, all previously misidentified as *Pomolobus chrysochloris* (USNM 36424, 36620, 36835, and 62225), are no doubt in their first year; they were collected from: the Stone River at Nashville and the Clinch River at Clinton, Tennessee; the Washita River, and the Mulberry River at Mulberry, Arkansas. There is also at hand a specimen 105 mm TL (93 mm SL) taken in brackish water at Grand Isle, Louisiana. The young differ from their adults principally in having a more slender body and in possessing notably fewer gill rakers; the depth is 3.6–4.1 in SL and the gill rakers on the lower limb vary between 27–33. The increase in the number of gill rakers seems to be rapid, as five half-grown examples 175–215 mm TL (145–171 mm SL) from Pensacola already have 38–41 gill rakers.

"Numerous young, 8 or 9 inches in length" were reported for Pensacola, Florida, by Jordan and Gilbert (*73*: 247) as *A. sapidissima*, before *A. alabamae* had been recognized; five of these (USNM 30809) may be part of that material; they are typical of the Alabama Shad and are the only half-grown samples at hand. They, like the smaller American shad, are more slender than their adults and have fewer gill rakers; but the raker count in these is higher than in the smallest examples of *alabamae* reported above.

Spawning and Migrations. A. alabamae, like its close relative *A. sapidissima*, ascends streams in spring and spawns in fresh water. Sexually mature Alabama Shad, observed at Keokuk Dam, Iowa, in 1915 and 1916 from the early part of May to the middle of July, were in upstream migration to spawn but were stopped by the dam, except for a few that might have passed through the lock (*27*: 169). Coker believed there were enough there "to support a substantial fishery." Other runs in the spring of the year have been reported for the Black Warrior River (Tuscaloosa) and at Mobile, Alabama (*32*: 127); the Kanawha River at Montgomery, West Virginia; and the Ohio River at the falls, Louisville, Kentucky (*31*: 275–276). An apparently reliable source reported still other runs to Dr. Evermann—for the Ohio River about 30 miles below Louisville, Kentucky, and for the Mississippi River below Memphis, Tennessee.

In reply to a letter of inquiry addressed to the State Department of Conservation, Montgomery, Alabama, Mr. Ben. C. Morgan, Director of Conservation, replied (June 22, 1946):

> During the months of May and June, and sometimes earlier, we still have enormous quantities of fresh water shad which run or attempt to run up our main streams. I say attempt to run because of the fact that the Coosa, Tallapoosa, Tennessee, and Tombigbee Rivers all have locks and dams which prevent the shad from going further than these dams. Only last year on the Tennessee they banked below the dams by the millions and could be scooped with nets, which we do not allow, of course.

It seems highly probable that the young of this species descend the rivers to salt water at the end of their first summer, and it may be assumed, therefore, that the habits of the Alabama and American shads are very similar.

Food. It is well known that anadromous fishes, while migrating to their spawning grounds, do not feed regularly, if at all. The Alabama or Ohio Shad is no exception to this rule, for Mr. Stringham found that 105 of 163 stomachs examined at Keokuk, Iowa, were empty (*27*: 171). Others contained small quantities of insect and plant remains as well as some unrecognizable debris.

Variations. Although adults of *alabamae* and *sapidissima* differ widely in the number of gill rakers, the number in the very young is so similar in this respect that overlapping definitely occurs (see *Description*).

Examples taken from the Ohio River at the falls, Louisville, Kentucky, differed sufficiently from *alabamae* to be recognized by Evermann as a distinct species, which he named *Alosa ohiensis* (*31*: 277). He described *ohiensis* as differing from *alabamae* principally in a more elongated body and in the greater number of gill rakers on the first arch. However, the seven large specimens from the Ohio now at hand (including the type), though representing the extremes in the two characters mentioned, intergrade with the other 11 sexually mature examples (including the type material of *alabamae* from Tuscaloosa) from the several other localities in the Gulf drainage already listed. Therefore, *ohiensis* at most is only subspecifically distinct. It is herein regarded as a synonym of *alabamae*.

Commercial Importance. This species has never been an important foodfish; only small catches have been recorded a couple of times in the statistical reports of the former U. S. Fish Commission: for 1889, 6,955 pounds from the Ohio River in Indiana and Kentucky (1902: 667); and for 1902, 150 pounds from Alabama (1905: 416). No later catches seem to have been reported. By correspondence with Herman O. Hessen, U. S. Fish and Wildlife Service, Louisville, Kentucky, it was learned that no one now (1946) fishes for the "Ohio Shad" at that place, though a few are taken incidentally each spring. That these Shad were, and perhaps still are, numerous enough in some places to be taken in considerable quantities is evident, but no special effort is apparently made to catch them. In fact, the fish seem to be regarded in some localities as too bony for human use. At least one fisherman interviewed by Mr. Hessen at Louisville, Kentucky, stated that the fish were so bony that fishermen threw them on the bank and made no effort to sell them. Nevertheless, the food qualities of this Shad, tested by those who are familiar with the delicious American shad, have been found not at all inferior (*31*: 275; *27*: 169).

It seems probable that Alabama Shad constitute at least a small unutilized food supply, but their actual abundance remains unknown. Evermann indicated that if proper equipment were used, considerable catches might be taken (*31*: 279); for example, a great increase in the catch resulted at Louisville, Kentucky, when surface-fishing seines were substituted for bottom-fishing seines. However, until people living on the shad streams of the Gulf drainage recognize its delicious food qualities, there will be little demand; hence no special effort to catch them will be made. Because of the many dams constructed across rivers, barring them from the spawning grounds, a decrease in abundance is no doubt taking place.

Despite an unutilized supply of Alabama Shad in streams tributary to the Gulf of Mexico, large shipments of American shad fry, *A. sapidissima*, were liberated in those streams (*2*). However, no American shad are included among the rather numerous specimens examined, nor has any authentic record of their occurrence in those streams been found. Indeed, Alabama Shad seem to be referred to as "Potomac shad" by fishermen who believe they are the progeny of American shad planted by the former U. S. Fish Commission.[29] But it seems quite certain that the introduction failed.

Range. The Alabama Shad is represented by specimens in the National Museum and has been recorded for all the principal streams tributary to the Gulf of Mexico (exclusive of the Pearl River), from the Mississippi eastward to the Choctawhatchee River, about 50 miles east of Pensacola, Florida. A 105-mm specimen from Grand Isle, Louisiana, is also at hand. In the Mississippi Valley it is known from as far west as Hot Springs, Arkansas, and northward to Fairport, Iowa, and Montgomery, West Virginia.

Synonyms and References:

Clupea sapidissima Jordan and Gilbert (not of Wilson), Proc. U. S. nat. Mus., 5, 1882: 247 (meas., counts of half-grown examples from Pensacola, Florida); Bollman, Proc. U. S. nat. Mus., *9*, 1886: 462 (two large ones, Escambia R., Alabama).

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[29] Fishermen generally do not seem to distinguish Alabama Shad from skipjack herring, *Pomolobus chrysochloris*; according to Coker (*27*: 165) they are referred to as "Government shad" by the fishermen at Keokuk, Iowa, apparently in the belief that they are the result of these plantings.

Clupea chrysochloris Meek (not of Rafinesque), Bull. U. S. Fish Comm., *14*, 1894: 85 (Mulberry, Arkansas; USNM 62225 *A. alabamae*).

Alosa alabamae Jordan and Evermann *in* Evermann, Rep. U. S. Comm. Fish. (1895), 21, 1896: 203 (orig. descr.; type local. Black Warrior R., Tuscaloosa, Alabama; types USNM 47689 [♀] and 47690 [♂]; cf. *A. sapidissima*); Evermann and Kendall, Bull. U. S. Fish Comm. (1897), *17*, 1898: 127 (distr.); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (3), 1898: 2810, figs. 192, 192a (descr., refs.); Regan, Ann. Mag. nat. Hist., (8) *18*, 1916: 9 (refs., diagn.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 43 (range, ref.).

Alosa ohiensis Evermann, Rep. U. S. Comm. Fish. (1901), 27, 1902: figs. 1 and 2, ♀ and ♂ *ohiensis*; figs. 3 and 4, ♂ and ♀ *alabamae* (orig. descr.; type local. Ohio R., Louisville, Kentucky; types USNM 50469; cf. *alabamae* and *sapidissima*; distr.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 42 (range, ref.); Coker, *et al.*, Bull. U. S. Bur. Fish (1929), *45*, 1930: 169 (Keokuk, Iowa 1915, 1916; influence of dam on migr.; an unused food).

Alosa alabamae ohiensis Regan, Ann. Mag. nat. Hist., (8) *18*, 1916: 9 (ref., diagn.).

Genus *Pomolobus* Rafinesque 1820

Alewives, River Herring

Pomolobus Rafinesque, West. Rev. Misc. Mag., *2*, 1820: 170; Ichthyol. Ohiensis, 1820: 38; genotype by monotypy, *Pomolobus chrysochloris* Rafinesque.

Generic Synonym:

Alausella Gill, Proc. Acad. nat. Sci. Philad., Suppl., 1861: 54; Proc. Acad. nat. Sci. Philad., 1861: 36; genotype by monotypy, *Clupea parvula* Mitchill equals probably young of *Clupea pseudoharengus* Wilson.

Characters. Body oblong, compressed. Bony scutes strong, with sharp points; a sharp edge on median line of chest and abdomen. Cheek generally longer than deep, about as long as deep in *P. mediocris*. Mouth large. Maxillary extending to or beyond middle of eye. Upper jaw with a more or less definite median notch in adults. Lower jaw projecting or included, its upper margin within the mouth rising more or less abruptly. Teeth in jaws not entirely wanting in adults; present at least anteriorly in lower jaw, though rudimentary in some species; present on median line of tongue; wanting on vomer. Dorsal with 15–21 rays, the last one not produced, its origin nearer to tip of snout than to base of caudal. Anal with 16–23 rays, the last one not especially enlarged. Pelvic with 9 rays. Vertebrae 46–55.

Remarks. Two members of this genus, *mediocris* and *chrysochloris*, are close to the American species of *Alosa* in the general structures about the head, except that the lower jaw projects beyond the upper one; they differ strongly, however, in having fewer gill rakers, which do not increase in number with age (18–24 on lower limb). The other two species, *aestivalis* and *pseudoharengus*, herein recognized, agree more or less with the species of *Alosa* in the number of gill rakers (38–51 on lower limb) and in having the lower jaw included; they differ, however, in having much shallower cheeks, which are much longer than deep, and in having the upper margin of the lower jaw rising abruptly within the mouth to form a more or less obtuse angle.

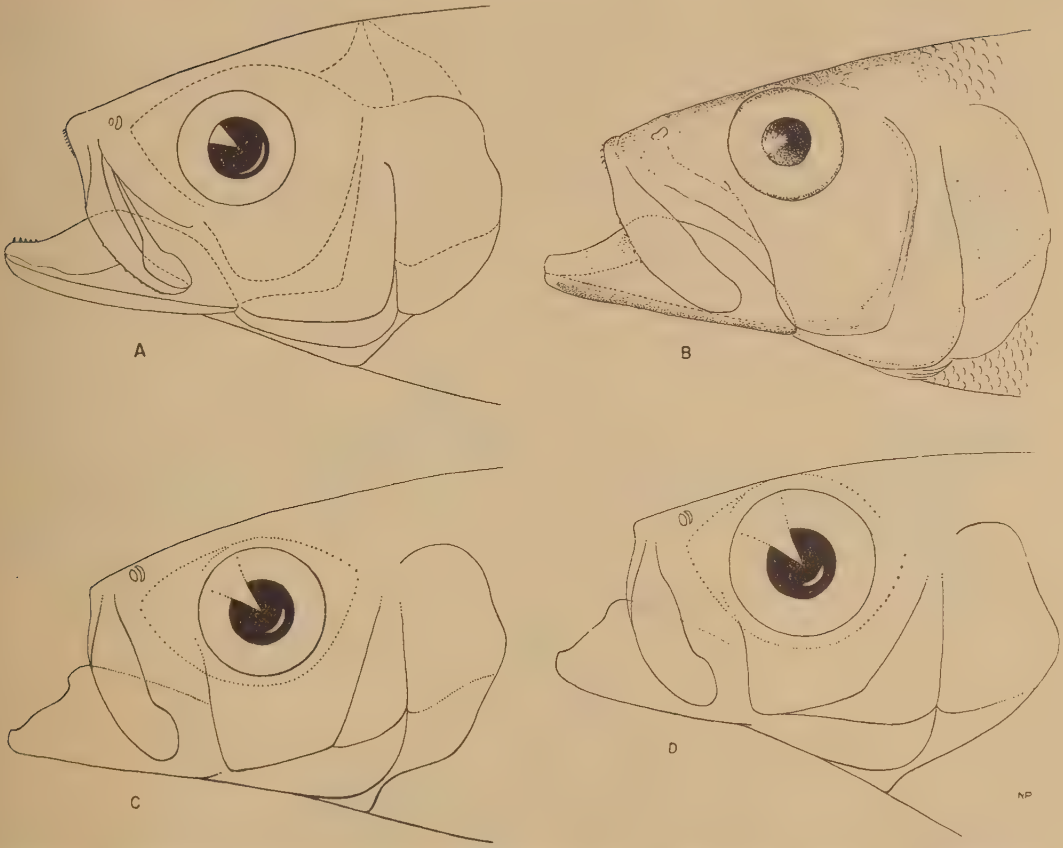

FIGURE 76. *Pomolobus* heads, showing shape of mandible and cheek. A, *chrysochloris*, 54 mm TL, USNM 9424; B, *mediocris*, 122 mm TL (after Hildebrand and Schroeder); C, *aestivalis*, 45 mm TL, USNM 69834; D, *pseudoharengus*, 48 mm TL, USNM 69833. A drawn by Ann S. Green, B by Louise Nash, C, D by Nancy D. Patton.

Range. Three species occur in the Atlantic, from Nova Scotia to northern Florida, and one occurs in the Gulf of Mexico and tributary streams as far west as Corpus Christi, Texas, ranging northward to Minnesota (see Key).

Key to Species

1a. Lower jaw strongly projecting, extending nearly or quite into dorsal outline of head (Fig. 76 A, B); only 18–24 gill rakers on lower limb of first arch, not increasing in number with age.

  2a. Greatest depth of body usually less than length of head, 3.5–4.1 (usually 3.8–4.0) in SL; teeth present in jaws at all ages, those in lower jaw prominent; bluish green color of back ceasing abruptly, not blending into the silvery color of side; no spot at shoulder. *chrysochloris* Rafinesque 1820, p. 315.

2b. Greatest depth of body usually greater than length of head, 3.0–3.75 (usually 3.2–3.6) in SL; teeth missing in upper jaw of adults, those in lower jaw very small (rudimentary); the grayish green color of back blending rather gradually into silvery color of the side; a dark spot at shoulder just behind head, often followed by several smaller spots. *mediocris* (Mitchill) 1814, p. 319.

1b. Lower jaw included or projecting but little, definitely not extending into dorsal outline of head (Fig. 76 C, D); gill rakers 38–41 on lower limb in adults, numerous at all ages.

3a. Diameter of eye generally about equal to length of snout in adults; 41–52 (most frequently 44–50) gill rakers on lower limb in adults; peritoneum usually black, sometimes pale with dusky dots; back in fresh examples bluish. *aestivalis* (Mitchill) 1814, p. 324.

3b. Diameter of eye longer than snout at all ages; 38–44 (most frequently 39–41) gill rakers on lower limb in adults; peritoneum pale, with dusky dots; back in fresh examples grayish green. *pseudoharengus* (Wilson) 1811, p. 332.

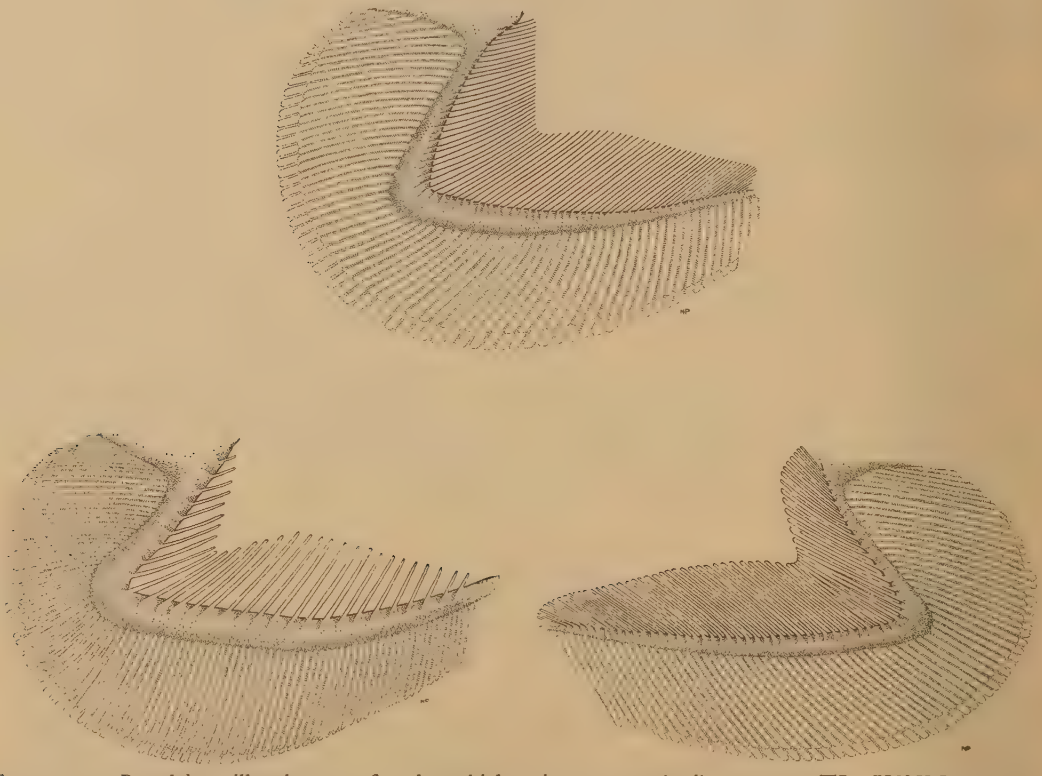

FIGURE 77. *Pomolobus* gill rakers on first branchial arch. TOP, *aestivalis*, 300 mm TL, USNM 125701; LEFT, *mediocris*, 310 mm TL, USNM 118156; RIGHT, *pseudoharengus*, 292 mm TL, USNM 117808. All drawn by Nancy D. Patton.

Pomolobus chrysochloris Rafinesque[30] 1820

Skipjack Herring, Skipjack, Golden Shad, Blue or Green Herring, River Herring

Figures 76, 78

Study Material. A total of 32 or more specimens, 115–420 mm TL, 95–341 mm SL; from Pensacola, Florida; Wetumpka, Montgomery, and Wheeler Reservoir, Alabama; Pascagula, Chickasawhay River, Pearl River, Eagle Lake, and Vicksburg, Mississippi; shrimp grounds (trawl) in Louisiana waters, Pass Manchac, and borrow pits in Mississippi River at Lake Providence, Louisiana; Mustang Island (Gulf side), Texas; St. Francis River, Mississippi River, Miles County, Arkansas; Lexington, Missouri; Mississippi River, Keokuk, and Fairport, Iowa; Cairo and Mississippi River, Victory, Wisconsin; and Fort Snelling, Minnesota; mostly in USNM, but some loaned by Miss Fannye A. Cook, Mississippi Game and Fish Commission, Percy Viosca, Southern Biological Supply Co., and Reeve M. Bailey, University of Michigan.

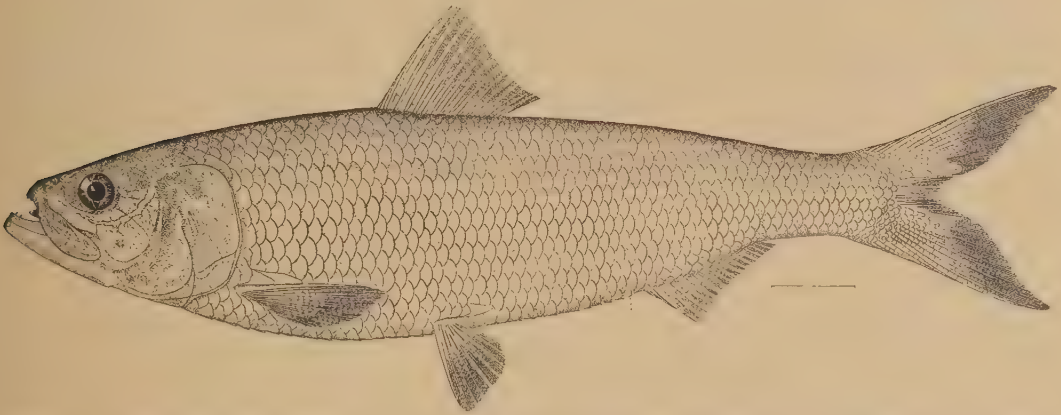

FIGURE 78. *Pomolobus chrysochloris*, 320 mm TL, Pensacola, Florida, USNM 30159. Drawn by S. Stearns.

Distinctive Characters. *P. chrysochloris* is closely related to *P. mediocris*, the hickory shad, of the Atlantic coast; the principal differences are indicated in the account of *mediocris* (p. 322). Both of these species are at once distinguishable from the other species of *Pomolobus* and from *Alosa* by the much smaller number of gill rakers.

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[30] Although this species has long been considered the genotype of *Pomolobus*, it may be questioned with good reason whether Rafinesque's descriptions of the genus and species are based on the Skipjack Herring or the Alabama shad, *Alosa alabamae*, or on both. If Rafinesque had both species, as suggested by his accounts, he confused them. In his generic account he said "Jaws without teeth." This is true of adult Alabama shad but not of the Skipjack. In fact, the latter has such prominent teeth in the lower jaw that they would scarcely be overlooked. Furthermore, in the specific account Rafinesque used the local name, Ohio shad, together with Gold shad and Green herring. Present-day fishermen certainly distinguish the two species and refer to *A. alabamae* as the shad and to *P. chrysochloris* as the herring (generally with a modifier, such as blue, green, or river).

When listing local names, Rafinesque remarked: "A fine fish from twelve to eighteen inches long. Flesh esteemed, white and less bony than the shad." The comparison evidently is with the American shad. The remark concerning the flesh seems to suit the Alabama shad, but not the Skipjack. On the other hand, the size given is more nearly that of the Skipjack than that of the shad; yet an 18-inch Skipjack would be an exceptionally large one. It is evident, then, that one cannot be certain as to the species on which Rafinesque's descriptions were based. Because of the doubt involved, it seems advisable to continue the use of *Pomolobus chrysochloris* for the Skipjack Herring. To do otherwise would lead to great confusion of both generic and specific names.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 95–341 mm SL.

Body: depth 24.2–28.4.
Caudal peduncle: depth 7.8–11.
Head: length 24.6–27.8.
Snout: length 4.8–6.3.
Eye: diameter 4.4–7.0.
Interorbital: width 3.8–4.8.
Maxillary: length 10.5–12.5.
Pelvic fin: length 10–12.6.
Pectoral fin: length 16–19.

Scales: 51–60, often difficult to count accurately.
Ventral scutes: 33–37, most frequently 34 or 35.
Gill rakers: on lower limb of first arch 20–24, most frequently 20–23.
Fin rays: dorsal 16–21, most frequently 18–20; anal 18–21, most frequently 19 or 20; pectoral 16 or 17, rarely 15.
Vertebrae: 53–55 (4 specimens).

Body slender, compressed, its greatest thickness generally somewhat less than half of its depth, its depth increasing with age and growth, usually equal to or less than length of head, 3.5–4.1 in SL.

Scales moderately adherent, with slightly irregular membranous margins, not preceded by striae; 15 or 16 longitudinal rows of scales on body between base of pelvic fin and anterior rays of dorsal. Ventral scutes well developed, 17–21 (most frequently 19 or 20) in advance of pelvics and 14–17 behind them.

Head 3.6–4.0 in SL. Snout 4.2–4.8 in head. Eye 3.8–5.9. Interorbital 5.4–7.5. Cheek, from lower rim of orbit, somewhat longer than deep. Mouth moderately oblique. Upper jaw with a definite median notch in adults. Lower jaw projecting strongly and extending into dorsal profile of head, its upper margin within mouth rising gradually, not forming an angle (Fig. 76 A). Maxillary broad, its width about 0.67 of length of snout, rounded posteriorly, reaching nearly or quite below posterior margin of pupil, 2.25–2.4 in head. Gill rakers not increasing in number with age. Teeth in anterior part of both jaws at all ages, those of lower jaw rather prominent; sockets present if teeth are broken; teeth on tongue prominent, in a rather large elongated patch.

Dorsal fin with slightly concave margin, its origin scarcely an eye's diameter in advance of pelvic and usually equidistant from margin of upper jaw and a vertical from last ray of anal; a scaly sheath on dorsal base, composed of a single row of scales and extending to 4th or 5th ray from end of fin. Caudal deeply forked, the lower lobe rather longer than the upper, about as long as head. Anal low, its margin nearly straight, its origin usually about equidistant between base of pelvic and base of caudal; a scaly sheath present on base. Pelvic fin inserted near ventral edge and usually nearer to base of pectoral than to origin of anal, 2.15–2.4 in head. Pectoral fin placed somewhat higher on side, 1.4–1.6 in head.

Color. Fresh specimens deep bluish green above, this color ceasing abruptly at level of upper margin of gill cover. Sides light green, with strong tinge of gold, especially on head, shading into the white of belly. No dark shoulder spot. Tips of jaws blackish. Dorsal fin yellowish, more or less dusky at base; caudal yellowish, tips of lobes dusky; anal and pelvic pale; pectoral pale, a dusky streak on inner side behind first ray. Peritoneum pale.

Size. Skipjacks are smaller in size than Alabama shad, with which they are more or less associated in the rivers; their length usually ranges between about 300–450 mm (12–18 in.).

Development. Although ovarian eggs 0.08–1.11 mm in diameter were observed, apparently no young under 107 mm (about 4.33 in.) were secured during Dr. Coker's extensive investigations at Keokuk, Iowa (*26*; *27*). Each of the smallest specimens at hand (UMMZ 122510, 128570), from the mouth of Elk River, Wheeler Reservoir, Alabama, and from the Mississippi River, Miles County, Arkansas, is about 40 mm (31 mm SL), apparently the smallest known. They differ from larger examples principally in being more slender, the depth of each being contained 4.75 times in SL. Furthermore, they have minute teeth on the margin of the maxillary, these persisting in examples up to 150 mm or so in length. The gill rakers, unlike those in some other species of the genus *Pomolobus*, do not increase in number with age and growth.

Spawning and Migrations. The spawning place and length of spawning are not fully known. For such information as is available we are indebted to Robert E. Coker, who, with assistants, carried on an extensive investigation at Keokuk, Iowa (*26*: 25, 26; *27*: 94, 165–169). They reported fish with large roe taken there on: April 29 and May 23 in 1914; April 29 and 30, May 24, June 5 and 23, July 1 and 2, and "various other dates" in 1915; and on May 23, June 3 and 17 in 1916. Fully mature fish, ripe for stripping, apparently were not included. Coker concluded his remarks on spawning as follows:

> Many attempts made during several years to find a particular place and time where and when river herring were clearly spawning met with no success, although various methods were tried. The problem proved unexpectedly baffling. Our data suggest only that the spawning season is prolonged, possibly beginning early in May; that the fish do not spawn in large aggregations; that during spawning operations they are not readily captured by ordinary methods of fishery; and that spawning is ended soon after the first of July.

It has not been proven that Skipjack are anadromous like most of the near relatives, even though Jordan said categorically, ". . . migrating from the Gulf of Mexico" (*71*: 40). However, they do enter salt and brackish water. Such a great "run" as was reported at Keokuk, Iowa, in the spring of 1914 as well as smaller runs in successive years and their apparent disappearance in September of each year do suggest extensive migration. However, Coker expressed the opinion that the migrations do not necessarily extend to extreme northern or extreme southern waters. This is in contrast to the strictly anadromous relatives, *Alosa sapidissima*, *Pomolobus aestivalis*, and *P. pseudoharengus* (except where the last species is landlocked), whose young leave the freshwater streams at the end of their first summer and do not return until they are ready to spawn.

Evidence has been set forth that *chrysochloris* reproduced in Lake Pepin after the closing of Keokuk Dam, an almost complete barrier to them. Dr. Coker said that without question there was a decided decline in the number of "River Herring" in this Lake during the three years immediately following the dam's construction, but some commercial catches there in 1926, 12 years after the dam was closed, convinced him that these fish were not rare; and several commercial fishermen stated that "the herring were coming back." On the basis of Dr. Coker's observations, it seems proper to conclude that *P. chrysochloris*, although migratory, does not need to have access to salt water to reproduce, and the species surely is not strictly anadromous. The presence of immature examples in a collection from brackish water as well as from the upper Mississippi also may be of some significance.

Food. Skipjack Herring are carnivorous (*35*: 49); the young feed on insects, the adults on fish. Coker stated that, of about 150 examples examined for food:

> Approximately one-third were empty; a little more than one-third contained fish, chiefly minnows, with some mooneyes, gizzard shad, and other fish not determinable; and less than one-third contained insects and larvae, principally May flies, with some caddis flies and others.

Habits. These are more active fish than most other clupeoids; they frequent rivers with swift currents and often leap from the water, a habit from which they have derived the name Skipjack. They leap in part for sport and in part for the pursuit of prey (*35*: 49). Coker remarked that they have, "a striking habit of leaping from the surface when feeding upon schools of minnows or in mere play."

Parasites. We know only that the larvae (glochidia) of the freshwater mussel *Fusconaia ebena* are parasitic on the Skipjack (see below).

Commercial Importance. The value of this species as a foodfish is negligible, for these fish are bony and not especially well flavored. No catches have been listed in the statistical reports of the U. S. government. However, they represent a very distinct economic asset as a host for the larvae of *Fusconaia ebena*, which has been regarded as the most valuable of all the pearly mussels of the Mississippi Basin because of its abundance in all the larger waters of strong current and because it yields a shell of the best quality for buttons (*27*: 166).

Range. Skipjack Herring range in the Gulf of Mexico from Pensacola, Florida, to Corpus Christi, Texas, and sometimes out into the Gulf, as off Breton Island, Louisiana. They also inhabit larger streams, occasionally lakes, or even borrow pits, of the Gulf drainage. They commonly range as far north in the Mississippi River as Lake Pepin, and occasionally to Fort Snelling, Minnesota, to Hudson, Wisconsin, and in the Ohio River to Pittsburgh, Pennsylvania. Apparently they are landlocked above Keokuk Dam, Iowa. Although Smith (*118*: 214) said that they were abundant in Lake Erie, and Jordan and Evermann (*72*, 1896: 425) as well as several others have stated that they reached Lake Michigan and Lake Erie through canals, Hubbs and Lagler (*62*: 27, ftn.) do not admit them to their list of fishes of the Great Lakes and tributary waters. The species apparently is most common in swift currents of large streams.

Synonyms and References:

Pomolobus chrysochloris Rafinesque, West. Rev. Misc. Mag., *2*, 1820: 171; and Ichthyol. Ohiensis, 1820: 39 (orig. descr.; type local. Ohio R.; type lost; length 12–18 in. attained; seldom ascend to Pittsburgh);[31] Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 425; 47 (4), 1900: fig. 187 (descr., size, distr., habits, value as food); Jordan and Evermann, Amer. Food Game Fishes, 1902: 101 (descr., range; Lakes Erie and Michigan erroneously included); Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 300, fig. (synon., range, habitat; reported to have reached Great Lakes through canals, but occur. there seems doubtful); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 195 (synon., descr., value as food, habits, distr.); Forbes and Richardson, Nat. Hist. Surv. Ill., Ichthyol., *3*, 1908: 48 (refs., descr., range, occur. in Illinois, size, habits); Coker, Rep. U. S. Comm. Fish. (1913), Append. 8, 1914: 25–28 (large schools below Keokuk Dam, Iowa; discus. migr. and ascent up spillways of dam; occur. above dam; spawn.); Regan, Ann. Mag. nat. Hist., (8) *19* (112), 1917: 299 (refs., descr., range); Jordan, Manual Vert. Anim. NE U. S., 1929: 40 (descr., range, habitat); Coker, Bull. U. S. Bur. Fish. (1929), *45*, 1930: 165, fig. 11 (below and above Keokuk Dam, Iowa, migr., spawn., econ. import.); Hubbs and Lagler, Bull. Cranbrook Inst. Sci., 18, 1941: 27 (not in list of Great Lakes fishes though reported there earlier); Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 25 (Texas coast, Colorado R. at Austin).

Meletta suoerii Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 375 (orig. descr.; type local. Wabash R., tributary of Mississippi R.); Bertin, Bull. Soc. zool. Fr., *66*, 1941: 23 (ident. of type).

Clupea chrysochloris Jordan and Gilbert, Proc. U. S. nat. Mus., *5*, 1882: 247 (descr.; records two specimens; from Galveston, Texas; and Pensacola, Florida); Jordan and Gilbert, Bull. U. S. nat. Mus., *16*, 1882: 266 (descr., range; Lakes Erie and Michigan apparently includ. erroneously); Jordan and Gilbert, Proc. U. S. nat. Mus., *9*, 1886: 11, 14 (Washita R., Arkadelphia, and Saline R., Benton, Arkansas); Bollman, Proc. U. S. nat. Mus., *9*, 1886: 462 (few from Escambia R., Alabama); Gilbert, Bull. U. S. Fish Comm. (1889), *9*, 1891: 158 (near mouth of Escambia R., Alabama); Smith, Bull. U. S. Fish Comm. (1890), *10*, 1892: 214, pl. 31 (Lakes Ontario and Erie); Evermann and Kendall, Bull. U. S. Fish Comm., *12*, 1894: 105 (Red R., Fulton, Arkansas; Galveston, Texas); Meek, Bull. U. S. Fish Comm., *14*, 1894: 78, 82 (White R. at Batesville, Little Red R. at Judsonia, Arkansas).

River herring, Coker, Bull. U. S. Bur. Fish., *45*, 1929: 91–104 (discus. abund. below Keokuk Dam, Iowa, 1914–1916; dam a barrier to fish).

Negative References:

Clupea chrysochloris Meek (not of Rafinesque), Bull. U. S. Fish Comm., *14*, 1894: 85 (Mulberry, Arkansas, but specimen USNM 62225 is *A. alabamae*).

Pomolobus mediocris (Mitchill) 1814

Hickory Shad, Hickory Jack, Bonejack, Fall Herring, Freshwater Taylor, Shad Herring

Figures 76, 77, 79

Study Material. Forty-three specimens, 105–460 mm TL, 82–354 mm SL, from Provincetown, Massachusetts; Noank, Connecticut; Long Island, New York; Beesley's Point, New Jersey; Annapolis, Love Point, Benedict, Barren Island, Lewistown, and Smith Point, all on or near Chesapeake Bay, Maryland; Potomac River, Washington, D. C.; Buckroe Beach and Lynnhaven Roads, on Chesapeake Bay, Virginia; Beaufort, North Carolina; and Brunswick, Georgia.

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[31] The data are from Richard E. Call's Ichthyologia Ohiensis (1899), "A verbatim et literatim reprint of the original, with a Sketch of the Life, the Ichthyologic Work, and the Ichthyologic Bibliography of Rafinesque," the original publications not being available to the author.

Distinctive Characters. See *Relationships* for differences between *mediocris* and *chrysochloris* (p. 322). From species of *Alosa* and other *Pomolobus* species, excepting *chrysochloris*, it is marked by the noticeably smaller number of gill rakers.

Description. Proportional dimensions in per cent of standard length, and counts, based on 43 specimens, 82–354 mm SL.

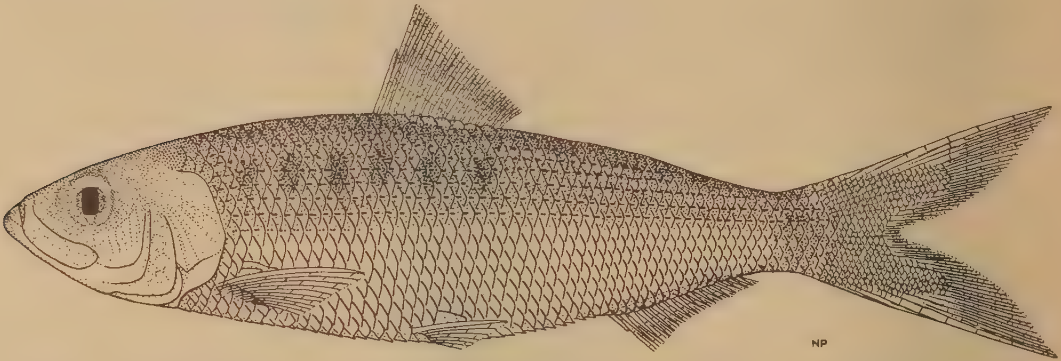

FIGURE 79. *Pomolobus mediocris*, 309 mm TL, Brunswick, Georgia, USNM 118156. Drawn by Nancy D. Patton.

Body: depth 26.7–32.8.
Caudal peduncle: depth 9.7–12.
Head: length 24.5–29.6.
Snout: length 5.9–7.5.
Eye: diameter 4.9–7.1.
Interorbital: width 3.9–5.4.
Maxillary: length 10.4–13.4.
Pelvic fin: length 10.6–12.4.
Pectoral fin: length 17–21.

Scales: 48–57.
Ventral scutes: 33–38, most frequently 36 or 37.
Gill rakers: on lower limb 18–23, usually 20 or 21.
Fin rays: dorsal 15–20, most frequently 17 or 18; anal 19–23, most frequently 20 or 21; pectoral 15 or 16.
Vertebrae: 54 or 55 (2 specimens).

BODY moderately slender, well compressed, its greatest thickness notably less than half of its depth, its depth rather greater in large than in small specimens, usually exceeding length of head, 3.0–3.75 in SL.

SCALES only moderately adherent, with definitely crenulate membranous margin, preceded by longitudinal striae; about 16 longitudinal rows of scales on body between base of pelvic and anterior dorsal rays. VENTRAL SCUTES moderately developed, 19–23 (usually 20–22) in front of pelvic fins, 12–17 (usually 13–16) behind them.

HEAD 3.4–4.1 in SL. SNOUT 3.7–5.0 in head. EYE 3.9–5.3. INTERORBITAL 5.5–7.0. CHEEK generally about as deep as long (Fig. 76 B). MOUTH oblique. UPPER JAW with a definite median notch. LOWER JAW projecting strongly and extending into dorsal profile of head (Fig. 76 B), its upper margin within the mouth rising gradually, not forming an angle (Fig. 76 B). MAXILLARY broad, its width somewhat more than half of length of snout, rounded posteriorly, reaching about to vertical from posterior margin of pupil, 2.0–2.4 in head. Gill rakers apparently not increasing in number with age. Teeth in the upper jaw absent in large examples 230 mm SL and upward, but present in smaller ones; present in lower jaw, becoming exceedingly small in large examples; those on tongue minute, in a small elongated patch.

Dorsal with slightly concave margin, its origin rather less than an eye's diameter in advance of pelvic, usually nearer to margin of upper jaw than to vertical from last anal ray; a sheath of scales on its base, consisting for the most part of more than one row of scales and extending nearly or quite to base of last ray. Caudal deeply forked, the lower lobe somewhat longer than the upper, fully as long as head. Anal low, its margin nearly straight, its origin about equidistant between base of pelvic and base of caudal; a sheath of scales on its base. Pelvic fin inserted near ventral edge and about equidistant between base of pectoral and origin of anal, 2.0–2.6 in head. Pectoral placed somewhat higher on side, 1.3–1.7 in head.

Color. Fresh specimen from Chesapeake Bay grayish green above, shading somewhat gradually into the iridescent silver of sides. Nape green, side of head brassy. Tip of lower jaw dusky. Dorsal and caudal dusky. Anal and pelvic plain, translucent. Pectoral slightly dusky. Narrow dark lines along rows of scales on upper part of side; missing on specimens less than 150 mm SL or so and most distinct in large examples that have lost their scales, the dark pigment being in the skin underneath the scales. A dark spot on shoulder; several obscure dark spots behind it, but missing in some examples. Peritoneum pale, but with scattered dusky punctulations.

Size. Hickory Shad definitely run larger in size than blueback and grayback herrings but smaller than the shad. A maximum length of 600 mm (24 in.) has been reported, but the usual size is much smaller. The commercial catches observed by me at Chesapeake Bay and at Beaufort, North Carolina, consisted mostly of fish varying between about 300–375 mm (12–15 in.) in length.

Reproduction, Development, and Migrations. Next to nothing is known about the breeding habits of Hickory Shad. Although it has been stated that they spawn in North Carolina in the spring, in the headwaters of streams (*119*: 121), spawners have never been seen in either fresh or salt water. In fact, many subsequent authors (*45*: 607; *16*: 106; *20*: 65) have accepted without reservation the opinion that Hickory Shad, like other local members of that genus, are anadromous. However, the only supporting evidence is that there are definite spring and autumn runs; in Chesapeake Bay, only stragglers are seen in the summer; in the spring they are first taken in the lower part of the Bay in March and progressively later farther up the Bay in late March and early April. Also, I have observed adults with well-developed roe in the Potomac above Washington during the spring, but these were not ripe and may have returned to salt water to spawn. The view that this fish does not enter salt water to spawn (*8*: 197; *37*: 95) is supported by Hildebrand and Schroeder (*59*: 84); among thousands of young clupeids collected during many years in Chesapeake Bay and its tributaries, in freshwater streams and estuaries, and in salt water out to 15 fms., they failed to find any Hickory Shad less than 15 mm (6.12 in.) long. Also, in the vicinity of Beaufort, North Carolina, they were absent from extensive collections made by Hildebrand and his associates with gear of various types, though adults were taken in the estuaries there in winter and early spring.

In short, Hickory Shad probably spawn in the spring, but it remains to be learned whether they spawn in fresh or salt water. However this may be, to the north of New York they are the most plentiful during autumn.

Food. Hickory Shad feed chiefly on small fish of various kinds. Their fish diet is supplemented by squid, small crabs, various small crustaceans, and by fish eggs (*59*: 84).

Enemies and Parasites. Little is known about the enemies of this species; but no doubt they are eaten by larger fish and are caught in limited quantities by man. Linton (*85*: 438) found individuals parasitized with nematodes (*Ascaris* sp.), cestodes (larval *Scolex polymorphus*), and trematodes (*Distomum appendiculatum*). Wilson (*136*: 12) found the Hickory Shad to be a host of the copepod *Lernanthropus brevoortiae.*

Relationships. Though closely related to *P. chrysochloris*, Hickory Shad have a heavier and less shapely (less streamlined) body; the depth in adults is greater than the length of the head (measured from margin of upper jaw); in *chrysochloris*, exclusive of very large or very fat specimens, the depth is equal to or less than the head. In *mediocris* the shield of scales on the dorsal fin base consists of more than one row of scales anteriorly and extends nearly or quite to the last ray of the fin, whereas in *chrysochloris* it is composed of only one row of scales throughout and is missing on the last four or five rays. The scales on the side of the Hickory Shad have a pronounced crenulate membranous border preceded by longitudinal striations, while in *chrysochloris* the border is only slightly irregular and the striations not evident. In *mediocris* there is only a slight ridge above the base of the pectoral, which ends at the tip of the axillary process; in *chrysochloris* a more pronounced depression (pocket) is provided for the pectoral fin, and the more prominent ridge above its base extends well beyond the axillary process of the pectoral.

In large Hickory Shad, 300 mm and upward, teeth in the upper jaw are missing, but in specimens at least up to 150 mm long they are present there; however, those in the lower jaw persist, though very small; the patch on the tongue is very small, and the teeth minute. In *chrysochloris* the teeth are consistently larger, persist in the upper jaw among adults, are large in the lower jaw, and the patch on the tongue is notably larger. Although the proportions and counts overlap, it is evident that Hickory Shad have a proportionately deeper body, deeper caudal peduncle, more anal rays, and fewer gill rakers than *P. chrysochloris.*

There are differences in color also, evident in preserved as well as fresh examples. Hickory Shad have a large dark spot behind the upper part of the opercle, often followed by several smaller dark spots, and the adults frequently have dark lines along the rows of scales on the upper part of the side. In *P. chrysochloris* these markings are missing, and the dark blue or grayish color of the back ends very abruptly, not tending to shade into the silvery color of the side, as in Hickory Shad.

Commercial Importance. Hickory Shad are of minor importance as foodfish, mainly because the meat is bony and is considered inferior in flavor. Their value is somewhat higher in North Carolina than elsewhere, because they are taken there during the winter when other fish are scarce. In 1940 or 1941, the following catches were reported: New England (all reports for Rhode Island and Connecticut), 25,800 pounds; the Middle Atlantic States (all reports for New Jersey), 4,400 pounds; the Chesapeake Bay states, 196,200 pounds, of which 22,000 pounds were taken in Maryland and 174,200 pounds in Virginia; and the South Atlantic states (all of which contributed), 371,500 pounds, of which 335,900 pounds were listed for North Carolina. It is evident, then, that the fishery is centered in Virginia and North Carolina. In the United States (1940, 1945, 1950–1953), catches have ranged between 0 and 25,800 pounds for southern New England, 200 and 4,400 pounds for the Middle Atlantic states, 86,000 and 264,000 pounds for Chesapeake Bay, and 273,000 and 970,000 pounds for the South Atlantic states.

Method of Fishing. The commercial fish are caught principally with seines and pound nets, the smaller quantities with gill and fyke nets. The fishery is not intense enough to affect greatly the abundance of these fish in nature. They take the hook occasionally and offer some sport in the spring, at least at Little Falls on the Potomac River. Anglers trolling for striped bass (*Roccus saxatilis*) and mackerel (*Scomber*) landed a number of Hickory Shad off the Merrimack River, Massachusetts, in 1932.

Range. The range of Hickory Shad extends from Florida to Maine. They are recorded for Campobello Island, New Brunswick (*52*: 47), but no record of their occurrence south of the St. Johns River in Florida has been brought to my attention. Though rare north of Cape Cod, they are apparently more numerous in southern New England than in the Middle Atlantic States and are most abundant in Virginia and North Carolina.[32]

Synonyms and References:

Clupea mediocris Mitchill, Rep. in part on Fishes of New York, 1814: 20 (orig. descr.; type local. presumably New York City; type lost); Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 450 (descr., New York Bay along Staten Island); McDonald *in* Goode, *et al.*, Fish. Fish. Industr. U. S., 1 (3), 1884: 607, pls. 216A, 216B (discus., names, distr., abund., econ. import., migr.).

Clupea mattowaca Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 451 (orig. descr.; type local. Long Island, New York; commonly caught in autumn, size).

Alosa mattowacca DeKay, N. Y. Fauna, Pt. 4, Fishes, 1842: 260, pl. 40, fig. 127 (descr., New York; fig. shows no projecting lower jaw, though descr. says "lower jaw longest").

Alosa lineata Storer, Proc. Boston Soc. nat. Hist., *2*, 1848: 242 (orig. descr.; type local. Massachusetts); Storer, Fish. Mass., 1867: 162, pl. 27, fig. 2 (descr., when and how taken, food value).

Clupea mattowocca Günther, Cat. Fish. Brit. Mus., *7*, 1869: 438 (refs., descr.).

Pomolobus mediocris Uhler and Lugger *in* Rep. Comm. Fish. Md., ed. 1, 1876: 159; ed. 2, 1876: 136 (descr., synon., Potomac R., size); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 425; 47 (4), 1900: fig. 188 (descr., range); 47 (3), 1898: 2810 (correc. of earlier acct.); Smith, Bull. U. S. Fish.

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[32] A listing of this herring among the clupeoid fishes of Brazil (*25*:190) was based on a specimen 170 mm long from an "ancient collection," without mention of the place of collection. The description offered suits *P. mediocris* quite well. However, as this herring does not seem to occur on the Atlantic coast in semitropical waters, as in southern Florida, one is justified in questioning whether it actually was taken in Brazil.

Comm. (1897), *17*, 1898: 91 (Woods Hole, Massachusetts); Smith and Bean, Bull. U S. Fish Comm. (1898), *18*, 1899: 183 (Potomac R., weight); Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 55 (refs., Florida); Linton, Bull. U. S. Fish Comm. (1899), *19*, 1901: 438 (parasites); Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 301, fig., also color pl. (synon., names, size, New York); Jordan and Evermann, Amer. Food Game Fish., 1902: 102, fig. (names, habits, size, descr.); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 197 (synon., descr., local and techn. names, size, habits, range); Fowler, Rep. N. J. St. Mus. (1905), 2, 1906: 95, 2 figs. (descr., habits, size, refs.); Smith, N. C. geol. econ. Surv., *2*, 1907: 121, fig. 40 (refs., descr., range, North Carolina, names, econ. import.); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7*, 1908: 37 (refs., New Engl. locals.); Halkett, Check List Fish. Canada, 1913: 47 (Campobello I., New Brunswick); Regan, Ann. Mag. nat. Hist., (8) *19* (112), 1917, 300 (descr.); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40* (1), 1925: 105 (descr., size, range, food, Gulf of Maine); Wilson, Proc. U. S. nat. Mus., *64* (17), 1925: 12 (host of parasitic copepod); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43* (1), 1928: 83, figs. 42, 43 (synon., descr., distinct. char., food, migr., other habits, Chesapeake Bay); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 40 (diagn., range); Truitt, Bean, and Fowler, Bull. Md. Conserv. Dep., 3, 1929: 49 (descr., Maryland); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 65 (relation., range, habits, size); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 42 (range, synon.).

Doubtful References:

Clupea pusilla Mitchill, Rep. in part on Fishes of New York, 1814: 20 (orig. descr.; type local. presumably New York; type lost); Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 452 (descr.).

Negative Reference:

Pomolobus mediocris Evermann and Hildebrand, young, not of Mitchill, but *P. pseudoharengus* (Wilson), Proc. biol. Soc. Wash., *23*, 1910: 158 (Chesapeake Bay locals.).

Pomolobus aestivalis (Mitchill) 1814

Blueback Herring, Blueback, Glut Herring, Blue Herring, Summer Herring, Blackbelly, Alewife, Kyak

Figures 69, 76, 77, 80, 81

Study Material. A total of 75 or more specimens, 33–295 mm TL, 27–240 mm SL; from off Liverpool, Nova Scotia; Freeport and Portland, Maine; Gloucester, Cape Cod, and Woods Hole, Massachusetts; Noank, Connecticut; New York Bay, N.Y.; Washington, D. C.; Chain Bridge, Bryans Point, Plum Point, Havre de Grace, Patuxent River, Barren Island, and Smith Point, Maryland; Rappahannock River and Buckroe Beach, Virginia; Avoca and Beaufort, North Carolina; and St. Johns River, Florida; in USNM collections.

Distinctive Characters. See *Relationships*, p. 330.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 27–240 mm SL.

Body: depth 21–33.5.
Caudal peduncle: depth 8.0–10.5.
Head: length 21.5–30.
Snout: length 3.8–5.8.
Eye: diameter 5.0–9.5.
Interorbital: width 3.7–6.0.
Maxillary: length 9.0–13.2.
Pelvic fin: length 9.4–13.6.
Pectoral fin: length 15.5–21.5.

Scales: 46–54.

Ventral scutes: 31–36.

Gill rakers: on lower limb 41–51 in adults, most frequently 45–50.

Fin rays: dorsal 15–20; anal 16–21; pectoral 14–16.

Vertebrae: 49–53 (35 specimens).

Body rather slender, moderately compressed, its greatest thickness about 2.5 in the depth, its depth 3.0–4.6 in SL.

Scales only moderately adherent, generally lost in young; with crenulate membranous edge preceded by scarcely visible striae: about 13 or 14 longitudinal rows of scales on body between base of pelvic and base of dorsal. Ventral scutes rather strong, 18–21 in advance of pelvic fins and 12–16 behind them.

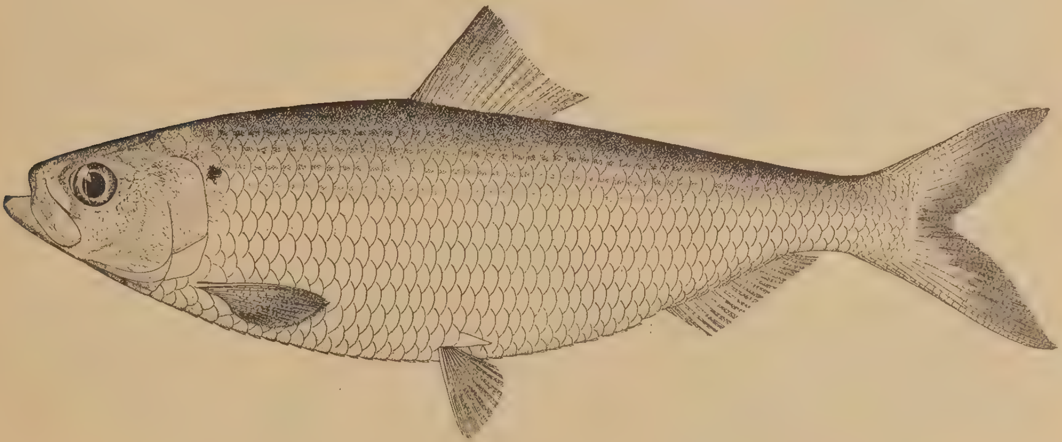

Figure 80. *Pomolobus aestivalis*, 265 mm TL, 10.6 inches, USNM 32639.

Head frequently equal to depth, 3.33–4.6 in SL. Snout 3.6–5.8 in head. Eye small, equal to or shorter than snout in adults, 3.0–6.0. Interorbital 4.0–7.0. Cheek notably longer than deep (Fig. 76 c). Mouth oblique. Upper jaw with a definite notch in adults. Lower jaw not projecting strongly, partly included, not entering into dorsal profile, its upper margin within the mouth rising abruptly and forming a more or less definite obtuse angle (Fig. 76 c). Maxillary broad, its greatest width about 75 % of length of snout, rounded posteriorly, reaching to, or more often somewhat beyond, vertical from middle of eye, 2.0–2.7 in head. Gill rakers at angle of first arch fully 0.75 of diameter of eye; increasing in number with age: 28–36 on lower limb in examples 30–49 mm SL, 30–39 in specimens 50–69 mm, 35–41 in specimens 70–89 mm, 38–44 in specimens 90–109 mm, 42–48 in specimens 110–129 mm, 42–50 in specimens 130–149 mm, and 42–52 in examples 190–260 mm (adults). Teeth on premaxillary exceedingly minute in young, missing in adults; those on free rim of maxillary rather prominent in young and often slightly evident posteriorly in adults;

those present on lower jaw persistent anteriorly, though not with free points in adults; a permanent narrow band of granular teeth on median line of tongue.

DORSAL fin with a definitely concave margin, its origin scarcely an eye's diameter in advance of the pelvic fin and usually a little nearer to margin of upper jaw than to vertical from last ray of anal; a narrow sheath of scales at base, incomplete, leaving base of last 4 or 5 rays exposed. CAUDAL deeply forked, the lower lobe the longer, a little longer than head. ANAL low, with straight margin, its origin about equidistant between base of pelvic and base of caudal; a narrow sheath of scales at base. PELVIC fin inserted near ventral edge and about equidistant between base of pectoral and origin of anal, 1.8–2.6 in head. PECTORAL somewhat higher on side, reaching about 0.66 of the distance to base of pelvic, 1.2–1.7 in head.

Color. Fresh fish bluish above and sides silvery. Rows of scales on back and upper part of side with more or less distinct dark lines in adults. Shoulder with a dark spot in the larger examples, generally missing in individuals less than 100 mm long. Fins plain, generally greenish or yellowish in life. Peritoneum usually, though not always, dark.

Size. Bluebacks are known to attain a length of about 380 mm (15 in.) and a weight of approximately 13 ounces. However, the usual size of these fish in commercial catches as observed in the Chesapeake Bay area is under 300 mm (12 in.) and a half pound or less in weight.

Development and Growth. The eggs and early young were described by Kuntz and Radcliffe from material taken at Woods Hole, Massachusetts (76: 123–126). The eggs are demersal, somewhat adhesive, semitransparent and yellowish, round, and approximately a millimeter in diameter. The development is rapid; hatching occurs at ordinary laboratory temperature about 50 hours after fertilization.

The newly hatched larvae (Fig. 81 A) are close to 3.5 mm long and quite slender. In about four days the yolk is all absorbed and the larvae have grown to a length of about 5 mm. The vent in these larvae, as in other clupeids, is situated far back, about at the beginning of the posterior fifth of the body.

The smallest specimen at hand, 20.5 mm long (16.5 mm SL), taken June 17 (1873) at Washington, D. C., is still very slender (Fig. 81 B), its depth about 7.5 times in SL. Its eye is rather longer than the snout, the maxillary extends nearly to the pupil, and the fins are all developed, the pelvic being inserted about under the origin of the dorsal. In a 25-mm specimen (20 mm SL), the depth is contained 5.0 times in the length, and the pelvic fin is well behind the origin of the dorsal (Fig. 81 C), as in adults. The 30-mm fish illustrated by Kuntz and Radcliffe (76: fig. 100) is much deeper than specimens of somewhat similar size now at hand, its depth being about 3.6 times in SL; in specimens from the Rappahannock River, Virginia, 34, 35, and 38 mm (28, 29, and 30 mm SL), the depth is respectively 4.6, 4.65, and 4.3 times in SL, and specimens even up to 45 and 50 mm long are more slender than the 30-mm one illustrated. If the proportions are correctly shown, it seems highly probable that the illustrated specimen is not this species.

When the young fish reach a length of about 80–90 mm they are usually pro-

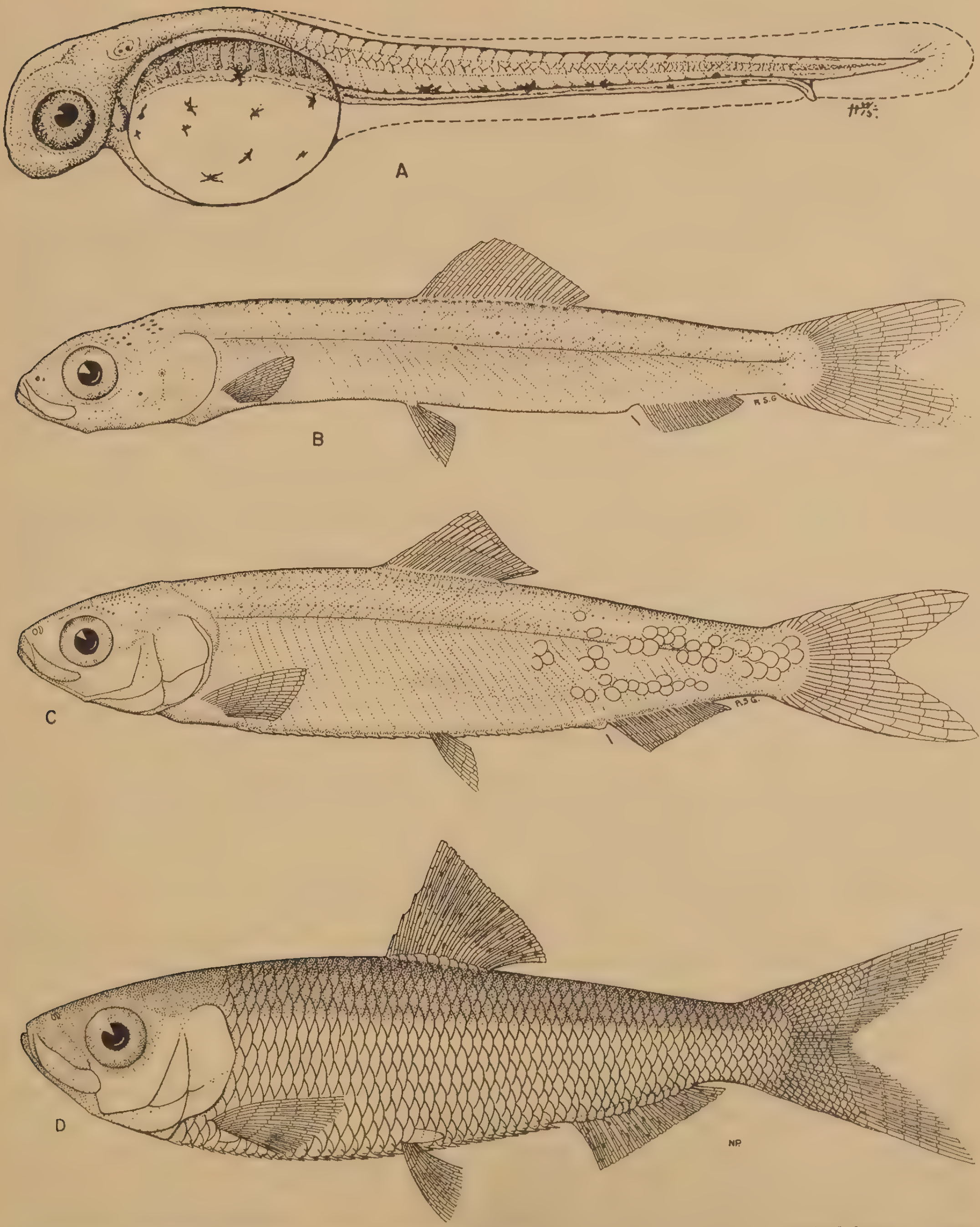

FIGURE 81. *Pomolobus aestivalis* growth stages; all from Potomac River. A, newly hatched larva, 3.5 mm, USNM 12830; B, young, still without scales, 20.5 mm TL, 16.5 mm SL, USNM 12830; C, young with scales developing, 25 mm TL, 20 mm SL, USNM 12830; D, young adult, 45 mm TL, USNM 69834. A drawn by Homer Wheelon; B, C by Ann S. Green; D by Nancy D. Patton.

portionately about as deep as large examples, though the diameter of the eye continues to exceed the length of snout until they are nearly full grown. The gill rakers (see *Description*) increase in number with age, quite rapidly in the young up to about 100 mm SL. It has been indicated also that the teeth are more prominent in the young than in the adult, and that they disappear entirely from the premaxillary with age.

In waters tributary to Chesapeake Bay, in the Potomac River in particular, where most of the young fish were collected and measured, the rate of growth of the young during their first summer and subsequently is shown in a table by Hildebrand and Schroeder (59: 88): 26 taken in June, 30–37 mm; 31 in July, 30–59 mm; 93 in August, 35–64 mm; 101 in September, 40–69 mm; 232 in October, 40–74 mm; and 181 in November, 50–74 mm. Collections of young of the same year-class from Chesapeake Bay consisted of: 276 taken in January, 65–119 mm long; 280 in February, 65–119 mm; 773 in March, 65–115 mm; and 8 in May, 95–120 mm in length. These data suggest that the young grow to a length of about 50–75 mm (2 or 3 in.) while living in fresh water and to a length of 65–120 mm (2.6–4.8 in.) when a year old.

Some older fish were taken in Chesapeake Bay, often in the same otter trawl hauls with the younger ones, but they are not separable into year-classes by the lengths given in the table referred to above. It is highly probable that, with few exceptions, these older and larger fish are approaching an age of two years. The collections consisted of: 8 taken in January, 160–194 mm in length; 15 in February, 150–209 mm; and 8 in March, 140–200 mm. If the six largest examples, which may be about three years old, are excluded, the range for the fish that apparently are two years old is 140–184 mm. If a length of around 200 mm is attained at three years of age, it is reasonable to assume that many individuals will attain a length of 250 mm (10 in.) when four years old. As adult gravid fish often are 250 mm and even less, it is highly probable that many individuals become sexually mature and perform their first migration to the spawning grounds at an age of four years.

Spawning, Migrations, and Habitat. Bluebacks are anadromous, but apparently they do not ascend rivers as far as their near relative, *P. pseudoharengus*. In the vicinity of Woods Hole, spawning takes place in fresh to slightly brackish ponds having an outlet to the sea; also, Bluebacks enter at least the mouths of the larger rivers in New England.

This species usually arrives in the coastal waters a month or so later than *pseudoharengus*—for example, in the lower parts of Chesapeake Bay during the first half of April and in the upper sections of the Bay about two weeks later. Hildebrand and Schroeder (59), in speaking of the migration in Chesapeake Bay, stated: "The peak of the catch of bluebacks is usually taken between April 1 and 20 in the lower bay. The numbers decrease throughout May, until after June 1 only stragglers are caught." The time of arrival varies from year to year by as much as a couple of weeks, depending upon the temperature of the water, which apparently must reach about 70° F before Bluebacks will enter. Northward, of course, the runs take place correspondingly later.

Spawning apparently begins very soon after the fish enter fresh or brackish water. Judging from the size and development of the young and from what is known concerning their migration locally, spawning in the Potomac seems to be confined principally to the last half of April and the first half of May. Ripe fish were taken in July (1915) at Woods Hole, Massachusetts (*76*: 123); while most of the females were spent, considerable numbers of each sex were still unripe.

The spent fish, in the Chesapeake Bay area at least, return to the ocean soon after spawning (*59*: 86). In the Gulf of Maine, "the spent fish, like alewives, return to the sea shortly after spawning. Probably these are the bluebacks taken at Woods Hole and north of Cape Cod in September and October. The winter home of our bluebacks is unknown; probably like their relatives the sea herring, they move out from land and pass the cold season near the bottom" (Bigelow and Welsh, *16*: 113). The capture of seven large Bluebacks, up to 375 mm (15 in.) in length, on March 5 (1931) about 70 miles off Barnegat, New Jersey (*14*: 377), and the acquisition of nine fish by me January 18 (1926) in the market and reported by the dealer to have been taken off Beaufort Inlet, North Carolina, with "sink nets" (often operated in fairly deep water), tend to substantiate the view that they winter near the bottom. The latter fish, one female and eight males, all contained well-developed gonads. Bigelow and Welsh reported that large schools of Bluebacks are often seined off the coast of Maine "outside the islands" during summer and fall and that they consist mostly of "2-year-old fish not yet sexually mature" (*16*).

In the Potomac, where the young are abundant below Little Falls throughout the summer, fish 20 mm long were taken there as early as June 17, and none less than 30 mm was secured in July. Upon the approach of cool water, October and November in the Chesapeake Bay area, the young leave the fresh waters; they are then about five to six months old, and the greater part of them passes through Chesapeake Bay and out to sea in company with graybacks and shad of a similar age. However, some of them stop to spend their first winter in the deeper parts of the Bay, and a few seem to spend their second winter there. However, no young have been listed as occurring offshore, from Chesapeake Bay southward. Pearson did list "*Pomolobus* sp." as having been "observed" in trawl catches off the coast of Virginia and North Carolina (*103*: 18); whether these fish were young or adults was not stated.

Food. The food (*16*: 113) consists of plankton, copepods, pelagic shrimp, and young launce, and no doubt other fish fry.

Enemies. Undoubtedly the principal enemies of young Bluebacks are the predatory fishes inhabiting the fresh and brackish water they occupy the first several months of life. As they school and move into salt water en route to the sea, marine shore fishes undoubtedly take their toll. Welsh and Breder found that weakfish (*Cynoscion regalis*) taken at the head of the Acushnet River, Massachusetts, were gorged with the young of this species (*132*: 159). While the schools migrate from the sea to fresh water, large predatory fishes again must take a toll. Upon arrival in inshore waters and in bays and streams, large numbers are captured by man.

Parasites. The parasitic acanthocephalan *Echinorhynchus acus* and the nematode *Heterakis foveolata* have been listed (*123*: 742). A specimen with a large colonial hydroid, *Obelia commensuralis*, attached to its back has been reported for Beaufort, N. C. (*50*: 1–6).

Relationships. This species and *pseudoharengus* are closely related, but they differ prominently from *chrysochloris* and *mediocris* in the more numerous gill rakers. In general, *aestivalis* has a more slender body and a smaller eye than *pseudoharengus*. However, extensive overlapping occurs in a series of measurements of specimens from various localities, even though specimens of equal size are measured. But in any one area, as in Chesapeake Bay, the separation of the two species by a combination of the two characters mentioned generally is not difficult.

Northward, as in New England, the species run somewhat more slender, and often some northern graybacks are quite as slender as some of the Bluebacks from the southern part of the range. Although the proportionate size of the eye is a somewhat more reliable character than depth of body, some specimens are difficult to distinguish by this character also. Fresh examples generally are distinguishable by the color, the Bluebacks being bluish above, the graybacks grayish green. However, this difference in color disappears in preserved specimens. The Bluebacks usually have more gill rakers and vertebrae than the graybacks, but again intergradation occurs in each instance; and the use of the number of gill rakers is made more complex because of their increase in number with the age of the fish. The range and intergradation of all the proportions and enumerations mentioned are shown in the *Description*.

The peritoneum (lining of abdominal cavity) is said to be black in the Bluebacks and pale or pale gray in the graybacks. Because this character was supposed to be diagnostic, it has been used in keys many times, but in the numerous preserved specimens at hand, it was found unreliable; Herbert E. Warfel, who has worked with *Pomolobus* in Connecticut, has informed me (verbally) that this character is unreliable in fresh material also. It cannot be trusted, because the peritoneum in the Bluebacks varies all the way from black to pale or pearly gray.

It is evident from the foregoing discussion that *aestivalis* and *pseudoharengus* often can be distinguished only by a combination of characters, and that, even then, some troublesome examples occur, with small specimens more difficult to identify than large ones.

Abundance and Commercial Importance. The relative abundance of the Bluebacks and graybacks is not definitely known. Although many fishermen recognize the two species, they are not separated in the market, and the catches are listed merely as "alewives" in the government's statistical reports. It has been stated that the two species are about equally abundant in Chesapeake Bay and that each contributes an equal share to the commercial catch (*59*: 91); also, the Bluebacks are more abundant than the graybacks in the southern states and less numerous northward (*72*, 1896: 426). For the Gulf of Maine, Bigelow and Welsh found it difficult to arrive at a fair idea of the relative abundance of the two (*16*: 112); although it is generally agreed that the graybacks outnumber the Bluebacks in the northern part of their range, these authors were certain that large catches of Bluebacks were taken in the Gulf of Maine from time to time. In Nova Scotia the Bluebacks are rather uncommon and of slight value whereas the graybacks are common and of considerable economic importance (*129*: 55). Some statistics showing the combined catches of the two species, designated "alewives," are given in the account of the grayback (p. 338).

Fluctuations, Methods of Fishing, and Artificial Propagation. The remarks in the account of the grayback concerning fluctuations, effects of fishing, methods of fishing, and artificial culture, also apply in general to the Blueback.

Range. The range of this species extends all the way from Cape Breton, Nova Scotia (*15*: 107, ftn. 92), to the St. Johns River, Florida; it is the most numerous southward.

Synonyms and References:

Clupea aestivalis Mitchill, Rep. in part on Fishes of New York, 1814: 21 (orig. descr.; type local. presumably New York; type lost); Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 456 (descr.); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1882: 267 (cf. *C. vernalis* Mitchill = *C. pseudoharengus* Wilson; distinct. char., range, synon.); Bean, T. H., Proc. U. S. nat. Mus., 6, 1883: 366 (migr. in Chesapeake Bay); McDonald *in* Goode *et al.*, Fish. Fish. Industr. U. S., *1*, 1884: 579–588, pls. 209, 210 (hist. of nomencl., abund., geogr. distr., food, reprod., size, uses); Goode, Amer. Fishes, 1888: 393 (discus. relation. with *P. pseudoharengus*; names, abund., spawn., etc.).

Pomolobus aestivalis Jordan and Evermann. Bull. U. S. nat. Mus. 47 (1), 1896: 426; 47 (4), 1900: fig. 190 (cf. *P. pseudoharengus*; descr., synon.); Smith, Bull. U. S. Fish. Comm. (1897), *17*, 1898: 91 (Woods Hole, Massachusetts); Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 55 (St. Johns R., Welaka, Volusia Bar at Lake George, and Lake Monroe, Florida); Smith, N. C. geol. econ. Surv., *2*, 1907: 124, fig. 42, pl. 4 in color (synon., descr., range, habits, distinct. char.); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7*, 1908: 38 (refs., New England); Evermann and Hildebrand, Proc. biol. Soc. Wash., *23*, 1910: 158 (Bryans Pt., Maryland); Sumner, *et al.*, Bull. U. S. Bur. Fish. (1911), 31 (2), 1913: 742 (refs., Woods Hole, Massachusetts, parasites); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 300 (descr.); Kuntz and Radcliffe, Bull. U. S. Bur. Fish., *35*, 1918: 123, figs. 87–100 (develop. of egg and young; fig. 100 apparently not this species); Welsh and Breder, Bull. U. S. Bur. Fish. (1923), *39*, 1924: 159 (eaten by *Cynoscion regalis*); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40* (1), 1925: 110, fig. 45 (descr., size, range, Gulf of Maine); Nichols and Breder, Zoologica, N. Y., *9* (1), 1927: 39, fig. (distr. New York, s. New England, life hist., develop., size); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43* (1), 1928: 85, figs. 44–50 (synon., descr., cf. *P. pseudoharengus*, habits, growth rate of young, commerc. import., range, Chesapeake Bay); Truitt, Bean, and Fowler, Bull. Md. Conserv. Dep., 3, 1929: 50 (descr., Maryland); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 66, fig. (range, migr., spawn., size); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 42 (names, synon., range); Greeley, 24th Rep. N. Y. Conserv. Dep. (1934), Suppl., 9, 1935: 89, pl. 1 color (midsection of Hudson R.; cf. *P. pseudoharengus*); Vladykov and McKenzie, Proc. N. S. Inst. Sci., *19* (1), 1935: 55, fig. 29 (Nova Scotia); Gudger, Amer. Mus. Novit., 945, 1937: 1–6 (colonial hydroid on back); Greeley, 26th Rep. N. Y. Conserv. Dep. (1936), Suppl., 11, 1937: 73 ("summer herring"), 91 (abund. Hudson R., migr. of adults and young); Greeley, 28th Rep. N. Y. Conserv. Dep. (1938), Suppl., 15 (2), 1939: 82 (Long Island, New York); Bigelow and Schroeder, Bull. U. S. Bur. Fish., *48* (20), 1936: 327 (adults captured off Barnegat, New Jersey); Anonymous, Fish. Resourc. U.S., Senate Doc. 51, 1945: iii, 66, fig. (migr., range, commerc. import., methods of capture, causes for decline, remedies; consid. with *P. pseudoharengus*, not separately); Bigelow and Schroeder, Fish. Bull. (74) U. S. Fish Wildlife Serv., *53*, 1953: 106–107 (descr., habits, Gulf of Maine).

Pomolobus cyanonoton Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 305, fig. (synon., migr., time and place of spawn.); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 202 (synon., migr., local occur., common names); Fowler, Rep. N. J. St. Mus., 2, 1905: 98, figs. (male and female fig., dist. char., local occur., synon.).

Pomolobus sp. Pearson, Invest. Reps. U. S. Bur. Fish. (1932), *1* (10), 1936: 18 (in trawl catch).

Doubtful References:

Clupea fasciata LeSueur, J. Acad. nat. Sci. Philad., *1* (2), 1818: 233 (orig. descr.; type local. Sandwich, Massachusetts).

Alosa tyrannus De Kay (not of Latrobe), N. Y. Fauna, Pt. 4: Fishes, 1842: 258, pl. 13, fig. 38 (descr., occur. along coast; plainly not menhaden; descr. and fig. suggest *P. aestivalis*).

Alosa cyanonoton Storer, Proc. Boston Soc. nat. Hist., *2*, 1848: 242 (orig. descr.; type local. presumably Massachusetts); Storer, Fish. Mass., 1867: 161, pl. 27, fig. 1 (descr., names, occur.).

Pomolobus pseudoharengus (Wilson) 1811

Grayback,[33] Gray Herring, White Herring, Branch Herring, Bigeye Herring, Freshwater Herring, Sawbelly, Alewife, Kyak, Gaspereau

Figures 76, 77, 82, 83

Study Material. A total of 65 or more specimens, 30–330 mm TL, 23.5–268 mm SL, from Cape Breton, Nova Scotia; St. Andrews Bay, New Brunswick; Freeport and Portland, Maine; Falmouth and Woods Hole, Massachusetts; Noank, Connecticut; Long Island, New York; off Wildwood, New Jersey; and various localities in the Chesapeake Bay area.

Distinctive Characters. See *Relationships* under *aestivalis*, p. 330.

Description. Proportional dimensions in per cent of standard length, and counts, based on 65 or more specimens, 23.5–268 mm SL.

Body: depth 23.5–35.5.
Caudal peduncle: depth 8.5–12.
Head: length 22.6–34.8.
Snout: length 4.55–7.6.
Eye: diameter 5.0–12.
Interorbital: width 3.45–7.3.
Maxillary: length 10.5–15.
Pelvic fin: length 10.4–15.8.
Pectoral fin: length 14.6–22.6.
Scales: 42–50.
Ventral scutes: 30–36.
Gill rakers: on lower limb 38–43 in adults (occasionally 44).
Fin rays: dorsal 15–19; anal 17–21; pectoral 13–16.
Vertebrae: 46–50 (36 specimens).

Body compressed, its greatest thickness usually about 2.75 in its depth, the depth 2.8–4.25 in SL.

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[33] Grayback has been chosen as the leading name for *P. pseudoharengus* and blueback for *P. aestivalis* because these names in a measure are descriptive, distinctive, and are perhaps understood by more people within the range of the species than any others. Alewife certainly is not distinctive, as it sometimes includes both species mentioned, and in some places it is applied to the menhaden, *Brevoortia*. Branch herring and glut herring are distinctive in the Chesapeake Bay area, but these names are not well known northward. However, alewife is used in subsequent pages to include *both* of these species in citing commercial statistics, for the species are not separated in the market, where they are sold either as alewives or as river herring. [The American Fisheries Society recommends "Alewife" for *pseudoharengus*.—Y. H. O.]

SCALES only moderately adherent, often lost in preserved specimens; apparently not different from those of *P. aestivalis*; 14 longitudinal rows between base of pelvic and base of dorsal. VENTRAL SCUTES strong, 18–21 in advance of pelvics, 12–16 behind them.

HEAD less than depth, often fully by diameter of eye, 2.8–4.2. SNOUT 4.1–6.0. EYE large, longer than snout at all ages, 2.5–4.0. INTERORBITAL 4.0–7.3. MOUTH oblique, as in *P. aestivalis*; margin of lower jaw within mouth with a somewhat broader angle (Fig. 76 D); other characters about the mouth, including TEETH, as in *P. aestivalis*. MAXILLARY 1.8–2.8 in head. GILL RAKERS at angle of first arch about 0.66 of diameter of eye, increasing in number with age; 25–33 on lower limb in examples 30–49 mm SL, 32–36 in specimens 50–69 mm, 30–39 in specimens 70–89 mm, 35–38 in specimens 90–109 mm, 36–40 in specimens 110–129 mm, 36–40 in specimens 130–149 mm, and 38–44 in examples 210–270 mm (adults).

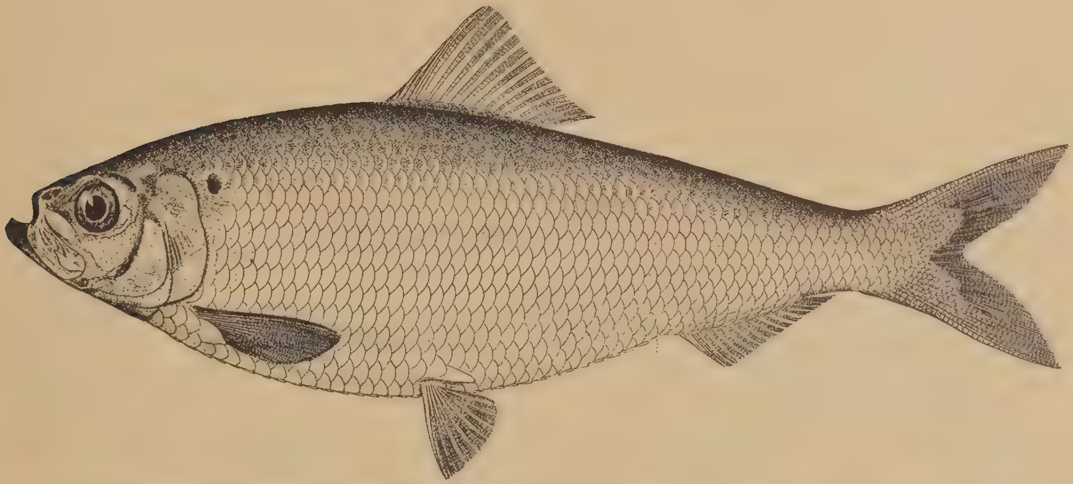

FIGURE 82. *Pomolobus pseudoharengus*, 300 mm TL, from a market in Washington, D. C., USNM 25197.

DORSAL fin with a straight to slightly concave margin, its origin definitely less than an eye's diameter in advance of pelvic fin and usually nearer to margin of upper jaw than to vertical from last ray of anal. CAUDAL deeply forked, the lower lobe a little longer than upper lobe, often exceeding head length by nearly the diameter of eye. ANAL low, with an almost straight margin, its origin about equidistant between base of pelvic and base of caudal. PELVIC fin inserted near ventral edge and usually equidistant between base of pectoral and origin of anal, 1.75–2.5 in head. PECTORAL fin somewhat higher on side, reaching about 0.66 of the distance to pelvic in adults and nearly to pelvic in some small examples, 1.1–2.0 in head.

Color. Fresh specimens, grayish green above. Sides silvery. Rows of scales on upper part of side sometimes with more or less definite dusky lines in adults. A small dark spot at shoulder, often missing in specimens less than 100 mm long. Fins all plain, slightly yellowish to green in life. Peritoneum generally pale or silvery, often with dark punctulations, and sometimes quite dusky.

Size. The Graybacks, like the bluebacks (*aestivalis*), attain a length of about 380 mm (15 in.) and a weight of about 14 ounces; the usual length of market fish, as observed in the Chesapeake Bay area, averaged only about 275 mm (11 in.) in length and about a half pound in weight.

Although Graybacks generally grow to a length of 275–300 mm (11–12 in.) in salt water along the Atlantic coast, their usual length in Lake Ontario (*118*: 188) is less than 150 mm (6 in.). The same writer mentioned fish only 100–125 mm (4–5 in.) long with roe as further evidence of stunted growth resulting from the local conditions under which the fish were living.

Development and Growth. The eggs are 1.25 mm in diameter and very glutinous when first laid, adhering to brush, rope, stones, piling, and other objects (*119*: 123). The incubation period extends over six days at a mean water temperature of 60° F.

Recently hatched larvae are very slender and extremely transparent, and have only a row of pigment spots on the side of the tail (*113*: 506, pl. 1, fig. 8). A two-day-old fish is about 5.0 mm long, and Ryder's figure shows the greatest depth, including the fin folds, to be about 10 times in TL, with the vent (as usual in clupeoid fishes) situated very far back at about the beginning of the posterior fifth of the body. This agrees very well with a larva of similar age and size described as *P. aestivalis* (*76*: 126).[34] The appendages (pyloric caeca), connected to the intestine near the stomach, are very small or wanting in the young but become greatly developed with age (*59*: 90).

The young reach a length of 15 mm when a month old (*16*: 109). On the smallest specimen at hand, 29 mm (22 mm SL), taken on June 18 (1873) at Washington, D. C., the depth is 4.0 times in SL; in other respects it already resembles the adult; the eye is notably longer than the snout and remains so throughout life. When the fish reach a length of about 100 mm, the proportionate depth is more or less the same as in adult fish.

The gill rakers (see *Description*) increase in number with age, this increase being especially rapid in the young up to about 100 mm SL. In this species, as in *P. aestivalis*, the teeth are more prominent in the young than in the adults and disappear from the premaxillary with age.

The young reach a length of 50–100 mm (2–4 in.) by autumn in streams tributary to the Gulf of Maine (*16*). This rate of growth is about the same as that shown by Hildebrand and Schroeder (*59*: 91) in a table based on collections made in streams tributary to Chesapeake Bay (especially the Potomac River). This table includes: 26 young for June, 45–74 mm; 105 for August, 50–84 mm; 134 for Sep-

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[34] Early larvae and some young adults, supposedly of *P. pseudoharengus*, were described and figured by Prince (*105*: 103–108, pls. 8, 10, in part). It seems doubtful whether his identifications were correct, for his drawings of young adults, compared with young adults from the Potomac, now before me, show the body to be much deeper and the mouth nearly vertical.

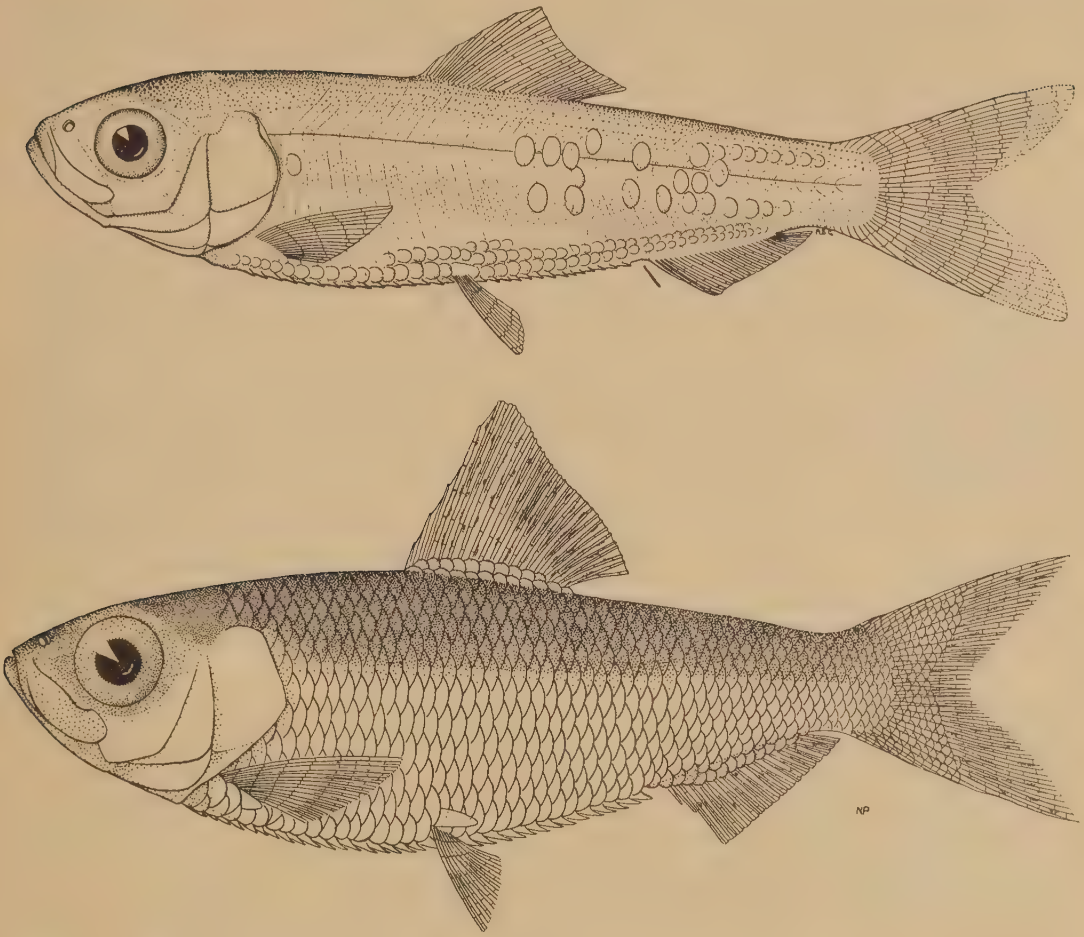

FIGURE 83. *Pomolobus pseudoharengus*, from Potomac River. TOP, young, showing scales developing, 29 mm TL, 22 mm SL, USNM 85668; BOTTOM, young adult, 47.5 mm TL, USNM 69833. UPPER drawn by Ann S. Green; LOWER by Nancy D. Patton.

tember, 50–79 mm;[35] 138 for October, 55–94 mm; 221 for November, 55–109 mm; and 19 for early in December, 60–79 mm TL. In Chesapeake Bay, young that appeared to be in their first winter, as judged from their small size, were 75–140 mm in January, 80–114 mm in February, and 80–145 mm in March. The young fry taken in the Bay during the winter varied so widely in length that it is clear they represented more than one year-class. The 262 older fish taken during the winter ranged between 115–224 mm, or 115–194 mm, if the three largest examples are excluded.

The foregoing data seem to show that the young of this species grow to a length of 55–109 mm (2.20–4.36 in.) while in fresh water, to about 65–145 mm (2.6–5.8 in.) at one year of age, and to about 115–195 mm (4.6–7.8 in.) at two years of age. Mature gravid fish often are only 250 mm (10 in.), or even less, and if a length of 200 mm (8 in.) or more is attained at three years of age, it is probable that many become sexually mature and perform their first migration to the spawning grounds when four years old. However, Bigelow and Welsh (*16*: 110) have reasoned that at least some of the fish in the Gulf of Maine area reach maturity at three years of age. This conclusion was reached because the "progeny" of adults used in restocking streams returned in the third year after the streams were restocked.

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[35] The largest young of the season evidently are not represented in this collection.

Spawning. This species is very prolific; a total of 644 females from the Potomac River yielded an average of 102,800 eggs per fish (*119*: 123). The time of spawning varies from some time in March in Chesapeake Bay to late April or May in Maine. They may spawn in running water or in ponds. Ripe fish have been taken many times in the Potomac, near Washington, where the eggs have been found adhering to fish traps and where young occur throughout the summer. Greeley has described their spawning in dense schools in fast water approximately two feet deep over a bottom of coarse stones, some sand, and gravel in the Poestenkill, at Troy, New York (*47*: 89). Around the Gulf of Maine, however, they spawn more commonly in ponds (including those behind barrier beaches), though probably not so exclusively as Bigelow and Welsh believed (*16*: 109).

According to Greeley (*47*: 89):

> The act of spawning is characterized by the whirling of a pair of fish in a close spiral, usually ending as they reach the surface with a splash and separate. The whirling is done rapidly and often only a flash of silver is to be seen. A number of spawning pairs were observed here [presumably the Hudson] by Dr. C. W. Greene and the writer. The sexes of the fish cannot be determined from the appearance of the fish in the water, but it was assumed that the fish seen whirling were mated pairs. It is probable that the male is on the outside of the spiral during the act of spawning and that the rapid circling is adopted for maintenance of contact as the eggs are shed and fertilized. Many eggs were scattered over the bottom and had drifted downstream where they were deposited by the current in slack water areas behind obstructions. The temperatures here May 16 (11 A.M.) were: air, 57 degrees; water 52 degrees.

Migrations and Habitat. This species is strictly anadromous. It has been common knowledge since colonial times that they run

> indifferently up rivers as large as the St. John (New Brunswick), the Merrimac and Potomac, or streams so small one can almost leap across, and only a few inches deep. In large rivers they may run far upstream . . . or their journey may be only a few yards, as it is in the artificial cuts that are kept open through barrier beaches to allow the fish access to fresh water ponds behind the latter (*15*: 103).

The Graybacks arrive in inshore waters a month or so ahead of the bluebacks and a week or two ahead of the shad. In Chesapeake Bay the first catches are made in late February or early March. In southern New England (Woods Hole, Massachusetts) they arrive sometime during March and are caught through March and April (*120*: 91). However, they do not reach the rivers of Maine until late April or early May and, as shown by the commercial catches, they are most numerous there during the last half of May (*16*: 109).

That the young return to the stream of their birth (the so-called "parent stream theory") was confirmed when the progeny of gravid adults planted in depopulated streams returned to these rivers three years after hatching (*16*: 110). This incident is also cited in a subsequent paragraph as a successful method of restocking streams. But a much more intensive study of this interesting question is needed before any categorical statement can be made as to how generally the parent stream theory applies in the case of the Graybacks (*15*: 103).

As in the case of bluebacks and shad, relatively little is known about the home of Graybacks in the sea. The capture of 18 adult Graybacks 70 odd miles off Barnegat, New Jersey, on March 5, 1931 (*14*: 327), suggests that the home may be some distance offshore. Since these adults were taken in March, they may have been en route to some nearby stream, hence it should not be assumed that the fish actually were taken from their usual abode in the sea. It has been surmised for some time that the Graybacks, as well as blueback herring and American shad, live quite a distance offshore from the rivers of their origin and that their migrations consist of inshore and offshore movements. This theory finds slight support in the discovery that different races spawn in different river systems. However, further study is needed.

The young, often with bluebacks and American shad of similar age, have been seen descending as early as June 15 in the more southerly streams fringing the Gulf of Maine. Successive companies of fry move out of the places where they were hatched, run down with the current throughout the summer and are at sea by autumn. In the Potomac, which the fish cannot ascend beyond Little Falls, the young remain abundant in the vicinity of Washington, D. C. Here they may be taken in the same seine hauls with bluebacks and American shad until October, when the main seaward migration takes place; however, some young remain in the river until November and a few linger until December. Most of the young apparently pass directly through Chesapeake Bay and out to sea, but some stop to spend their first winter in the deeper parts of the Bay, a few seem to remain for their second winter, and very few apparently stay there for their third winter.

The fish in the freshwater lakes endeavor to carry out the same spawning migration as those that inhabit the Atlantic coast, for the fish enter the shallow parts of the lakes and ascend the tributary streams to spawn.

Food. The food of the young while in fresh water apparently consists principally of diatoms, copepods, and ostracods. After they enter salt water, their chief diet seems to be shrimps and fish. Young 50–70 mm long, taken in fresh water, had fed principally on copepods and ostracods; and larger young, 83–178 mm long, caught in Chesapeake Bay, had continued to feed on copepods, though the larger ones had ingested principally mysids and fish (*59*: 90). Copepods, shrimps, and young squid were listed as the food of the young by Sumner, *et al.* (*123*: 72). Bigelow and Welsh (*16*: 110) have described their chief food as copepods, amphipods, shrimps, and appendicularians, small fish (such as herring, eel, launce, and cunner) as well as fish eggs and young of their own. Alewives often contain diatoms, even when adult. It is conceivable that diatoms could be screened from the water by the rather numerous, close-set gill rakers of adults.

It has long been known that anadromous fishes, as a rule, feed sparingly or not at all while ascending streams, and Graybacks are no exception to this rule. However, the spent fish feed ravenously on shrimp on entering brackish water along the coast, where anglers often hook them on an artificial fly (*16*).

Enemies. The young are undoubtedly preyed upon by various predatory fishes, turtles, snakes, and birds while they live in fresh water. When they begin to school and migrate out to sea, marine fishes and numerous other sea inhabitants very probably destroy many. When they re-enter shallow shore water as adults in great schools, large marine fishes of many kinds, finback whales, birds, and turtles, take a further toll. Upon arriving inshore and in the rivers, man—who captures great quantities for food—must be their chief enemy.

Parasites. The following have been listed by Sumner, *et al.* (*123*: 742): Acanthocephala (*Echinorhynchus acus*); cestodes (*Rhynchobothrium imparispine*); trematodes (*Distomum appendiculatum*, *D. bothryophoron*, *D. vitellosum*, and *Monostomum* sp.); and copepods (*Argulus alosae*, *Caligus rapax*, and *Lepeophtheirus edwardsi*).

Variations. Specimens from various localities within the range of this species along the coast (*Study Material*, p. 332) show a tendency toward a more slender body and a proportionately larger head toward the northern part of the range; and a limited number of specimens from fresh water, Cayuga Lake and Lake Ontario (proportions not used in *Description*), show this tendency to be even more pronounced there. In general, the fish from the northern part of the range (especially from Casco Bay, Maine), and more particularly those from fresh water, have the appearance of being more or less emaciated. However, insufficient specimens have been studied to determine the significance of the apparent differences mentioned. These differences may be of subspecific value, but more likely they are of only racial importance. The decrease in body depth in northern specimens makes their separation from *P. aestivalis* more difficult than identification of specimens from the southern part of the range.

Abundance and Commercial Importance. The relative abundance of *pseudoharengus* and *aestivalis* is discussed in the account of the latter (p. 330). It has been claimed by various writers that Graybacks are far less numerous now than during colonial days, or even a half century ago. The matter was summed up for the Gulf of Maine by Bigelow and Welsh (*16*: 108) in these words:

> During the past two centuries . . . its numbers have declined, and its range has been restricted, both by actual extirpation from certain streams by overfishing, by the pollution of river waters by manufacturing wastes, and by the erection of dams that it cannot pass. However, the alewife is still a familiar fish all along our coast, and yields an abundant catch in many of our streams.

These remarks also apply in a measure to fish in the more southern part of the range, though the decline apparently has been less pronounced southward.

The following statistics give the catches of Graybacks and bluebacks combined, under the name "Alewives." These records show in part the decline in their abundance during the past 50 years or so, but they also show that these fish are still abundant and of great economic importance. There has been no compensation for any variations in the "fishing effort"—the number of men, vessels, and amount and efficiency of the gear used—but it may be assumed that there was no decrease in this respect. Federal Government statistics, which have been taken at irregular intervals, report total catches in round numbers for the Atlantic coast of the United States as follows: 62,067,000 pounds in 1896, 52,061,000 in 1905, 35,809,000 in 1921, 35,290,000 in 1929, and 29,542,000 in 1941. The greatest proportionate decline took place in New England, for which the following catches are listed: 12,116,000 pounds in 1896, 8,429,000 in 1905, and 3,975,000 in 1924; however, from 1924 to 1941 the catch there remained fairly even.

South of New England the decline in abundance began later and was more gradual and less pronounced. For example, the Chesapeake Bay states (Maryland and Virginia), which have furnished a larger part of the total catch of "Alewives" than any other section of the coast since the beginning of this century, yielded a fairly even catch until about 1925. Thereafter a decline has been indicated by the statistics: 25,611,000 pounds in 1925, 21,129,000 in 1930, 18,884,000 in 1937, and 17,012,000 in 1941. The catch in the South Atlantic states, from North Carolina to Florida, is also very large, has fluctuated greatly, and has shown a slight downward trend: 15,857,000 pounds for 1897, 11,601,000 for 1902, 15,186,000 for 1918, 7,571,000 for 1923, 11,176,000 for 1929, 6,218,000 for 1937, 11,611,000 for 1938, and 9,116,000 for 1940. The over-all catch of the two species combined has ranged between 47,300,000 and 57,700,000 pounds for the United States (1940, 1945, 1950–1953), and between 6,250,000 and 41,000,000 pounds for Canada (1940, 1945, 1950–1952).

The Graybacks and blueback herring are still abundant. In fact, every state along the Atlantic coast exclusive of Pennsylvania, South Carolina, and Georgia, make substantial contributions to the catch, as do Nova Scotia and New Brunswick, Canada. Although these species are among the cheapest fish on the market, they furnish a substantial income because of their abundance. During recent years the annual yield to the fishermen from this fishery alone has been $ 400,000–800,000 in the United States, and $ 33,000–350,000 in Canada.

Most of the "Alewives" caught are salted, but an increasingly large part of the catch is sold in the fresh state. Although the flesh is quite bony, as in other herrings, it is delicious and is in demand whether fresh, salted, or smoked. At the salting houses the roe generally is separated for canning and the offal is made into fish meal and oil.

Although these fish have become common to abundant in some freshwater lakes, as in Lakes Ontario and Erie, they are of little economic importance there because of their small size. However, in 1892 Smith said that they were of more economic importance in Lake Ontario than is generally realized (*118*: 189). He pointed out that they had replaced more important foodfishes (young ciscoes and suckers) as bait for sturgeon and lake trout in the trawl-line fishery, that the young were used as bait in extensive sport fishing, and that many tons of those that wash ashore annually are used as fertilizer.

Fluctuations. Overfishing, pollution, and impassable dams in streams have been the chief factors in diminishing the abundance of "Alewives" in many localities, but all of these causes can be remedied at least in some measure by restocking suitable streams with gravid fish (*16*: 110; *et al.*). This has been done in Massachusetts localities, where, in the third year after the ripe fish were introduced, the progeny appeared in those streams.

It is not always easy to determine whether an increase or decrease in catch is due to the amount of fishing, to special conditions created by man, to successful or unsuccessful spawning, or to general conditions obtaining in nature. However, if the increase or decrease extends over a period of several years, reasonable conclusions may be reached. For example, the tremendous abundance of "Alewives" in the Chesapeake Bay area in 1908 and 1909, when the catches were about twice those in preceding and successive censuses (66,690,000 and 51,425,000 pounds), may be ascribed to especially favorable conditions during and probably after the spawning season. On the other hand, the general decline in the fishery in New England (discussed above), despite some fluctuations, quite surely was the result of adverse conditions created by man. Therefore, frequent censuses are necessary to show the status of this as well as other fisheries for the guidance of those entrusted with the promulgation of regulations for the conservation of the fishery.

Artificial Cultivation. "Alewives" have not been artificially propagated regularly because it has not been deemed necessary. However, in 1882 two million fry hatched by fish culturists were transported to the Colorado River, Texas (*45*: 586), an introduction that apparently was not successful. As already stated, another method of "planting" was successfully used in Massachusetts. Some depopulated streams in that state, which had been reconditioned and made suitable, were successfully restocked merely by releasing gravid fish. Graybacks apparently were unintentionally introduced into Lake Ontario when shad fry were planted there (*45*: 588; *118*: 188).

Methods of Fishing. "Alewives" are easily caught, chiefly with dip nets in New England. Pools are constructed about the mouths of rivers and the gravid fish are led into them by means of nets and stone diversions. Southward, as in the Chesapeake Bay area and in North Carolina, they are caught chiefly with pound nets. However, they are taken also with weirs, seines, gill nets, fyke nets, and a few with otter trawls.

Range and Distribution. The range of *pseudoharengus* extends from the Gulf of St. Lawrence and Nova Scotia, where it is common (*129*: 54), to North Carolina. It has been recorded for the St. Johns River, Florida, but the first report (*45*: 336), as *Clupea vernalis*, was apparently based on a *P. aestivalis* (USNM 17929, collected by Spencer F. Baird), now before me; and the second report, so far as known, by Lönnberg (*88*: 114), may be disregarded, for this species is too difficult to distinguish from *P. aestivalis* by a simple "observation." According to Smith, "extensive collections of fishes in the St. Johns River, in Florida, have failed to disclose its presence" (*119*: 122). Indeed, no specimens of this species from south of the Albemarle Sound area (where *aestivalis* is plentiful) have been found in the National Museum, and it was only sparingly represented among many specimens of *P. aestivalis* collected over a period of years in the Newport River and its estuary near Beaufort, N. C. Possibly this species does not occur south of North Carolina.

This species, as stated above under *Artificial Cultivation*, apparently was unintentionally introduced into Lake Ontario, whence it has spread to Lake Erie and to Lake Huron. It also inhabits Lakes Seneca and Cayuga, which it probably reached by natural means from the ocean (*45*: 116), and the Oswego River system in New York State (*46*: 95). It has remained common in Lake Ontario, has become common in Lake Erie, and has penetrated Lake Huron, where it is still rare (*62*: 27).

Synonyms and References:

Clupea pseudoharengus Wilson, in Rees' New Cyclopedia (Art. *Clupea*), *9*, undated, *ca.* 1811: no pages (orig. descr.; no local.; probably Philadelphia, Pennsylvania); Smith, Bull. U.S. Fish Comm. (1890), *10*, 1892: 187, pl. 29 (unintent. introd. in Lake Ontario, abund. there, diseases, mortal., uses).

Clupea vernalis Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 454 (orig. descr.; type local. New York; effects of mill dams on migr. to spawn); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1882: 267 (descr., range, synon.); McDonald *in* Goode, *et al.*, Fish. Fish. Industr. U. S., 1, 1884: 579–588, pls. 207, 208 (hist. of nomencl., abund., geogr. distr., migr., food, reprod., size, uses); Bean *in* Goode, *et al.*, Fish. Fish. Industr. U. S., 1, 1884: 588–593 (Lakes Cayuga, Seneca, and Ontario, origin in lakes, movements, enemies, fatal., capture); Ryder, Rep. U. S. Comm. Fish. (1885), 1887: 506, pl. 1, fig. 8 (descr. of egg and newly hatched young); Goode, Amer. Fishes, 1888: 393 (discus. with *P. aestivalis*, names, abund., spawn.).

Clupea megalops Rafinesque, Amer. Mon. Mag. (1817–1818), *2* (3), 1818: 206 (orig. descr.; type local. Delaware R.).

Meletta venosa Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 374 (orig. descr.; type local. New York); Bertin, Bull. Soc. zool. Fr., 66, 1941: 23 (ident. of types).

Pomolobus pseudoharengus Gill, Rep. U. S. Comm. Fish. (1871–72), 1873: 811 (names, range); Uhler and Lugger, Rep. Comm. Fish. Md., ed. 1, 1876: 158; ed. 2, 1876: 135 (descr., synon., habits, Maryland; *pseudoharengus* and *aestivalis* not distingu.); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 426; 47 (*4*), 1900: fig. 189 (descr., range, habits, synon.); Smith, Bull. U. S. Fish Comm. (1897), *17*, 1898: 91 (Woods Hole, Massachusetts); Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 302, with fig. (synon., names, occur. in lakes, migr., size, methods of capture); Bean, T. H., Bull. N. Y. St. Mus., *60*, Zool. 9, 1903: 199 (synon., descr., names, range, migr., size, growth of young, econ. value, methods of capture); Fowler, Rep. N. J. St. Mus., 2, 1905: 95 (figs. of male and female, descr., migr., synon.); Smith, N. C. geol. econ. Surv., *2*, 1907: 122, fig. 44, pl. 3 in color (synon., descr., range, migr., reprod., commerc. import., North Carolina, methods of capture); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7*, 1908: 38 (refs., New England); Sumner, Osburn, and Cole, Bull. U.S. Bur. Fish. (1911), *31*, 1913: 742 (refs., Woods Hole, Mass., food, parasites); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 300 (descr.); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40*, 1925: 107, fig. 44 (descr., size, range, Gulf of Maine, habits, food, commerc. import.); Nichols and Breder, Zoologica, N.Y., *9* (1), 1927: 38, fig. (distr. New York, s. New England, food, life hist., size); Hildebrand and Schroeder, Bull. U. S. Fish Comm. (1927), *43* (1), 1928: 89, figs. 51–52 (synon., descr., relation., growth of young, food, habits, commerc. import., range, Chesapeake Bay); Greeley, 17th Rep. N. Y. St. Conserv. Dep. (1927), Suppl., 1928: 95 pl. 3 in color (Oswego R. watershed); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 40 (diagn., range); Truitt, Bean, and Fowler, Bull. Md. Conserv. Dep., 3, 1929: 49, fig. 15 (descr., Maryland); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 65 (food, spawn., size); Greeley, 18th Rep. N. Y. Conserv. Dep. (1928), Suppl., 1929: 167 (common Lake Ontario, enters Niagara R.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 42 (names, synon., range); Greeley and Greene, 20th Rep. N. Y. Conserv. Dep. (1930), Suppl., 5, 1931: 82 (St. Lawrence watershed); Greeley and Bishop, 21st Rep. N. Y. Conserv. Dep. (1931), Suppl., 6, 1932: 78 (common Lake Ontario, St. Lawrence R., annu. mortal.); McKay, Copeia, 1934: 97 (first rec. for Lake Huron); Vladykov and McKenzie, Proc. N. S. Inst. Sci., *19* (1), 1935: 54, fig. 28 (Nova Scotia); Greeley, 24th Rep. N. Y. Conserv. Dep.

(1934), Suppl., 9, 1935: 89 (Mohawk-Hudson watershed, descr. of spawn.); Bigelow and Schroeder, Bull. U. S. Bur. Fish., *48* (20), 1936: 327 (adults off Barnegat, New Jersey); Greeley, 26th Rep. N. Y. Conserv. Dep. (1936), Suppl., 11, 1937: 90 (abund. Hudson R.; landlocked in reservoir and lake); Greeley, 26th Rep. N. Y. Conserv. Dep. (1937), Suppl., 12, 1938: 62 (Allegheny and Chemung watersheds); Greeley, 28th Rep. N. Y. Conserv. Dep. (1938), 13, 1939: 39 (in fresh water, Long Island, New York); Greeley, 28th Rep. N. Y. Conserv. Dep. (1938), Suppl., 15 (2), 1939: 82 (salt water, Long Island, New York); Greeley, 29th Rep. N. Y. Conserv. Dep. (1939), Suppl., 16, 1940: 68 (notes on alewife), 59–61 (abund. Lake Ontario; stunted growth in fresh water; annu. mortal., spawn.); Hubbs and Lagler, Bull. Cranbrook Inst. Sci., 18, 1941: 27 (range, Lakes Ontario, Erie, and Huron, where introd.); Anonymous, Fish. Resourc., U. S. Senate Doc., 51, 1945: iii, 66, fig. (migr. range, commerc. import., methods of capture, causes for decline, remedies, consid. with *P. aestivalis*); Bigelow and Schroeder, Fish. Bull. (74) U. S. Fish Wildl. Serv., *53*, 1953: 101 (descr., habits, Gulf of Maine).

Pomolobus pseudoharengus lacustris Jordan, Manual Vert. Anim. NE U. S., ed. 1, 1876: 265 (orig. descr.; type local. Cayuga Lake, New York; landlocked form subspecif. distinct from anadromous one).

Pomolobus mediocris Evermann and Hildebrand (not of Mitchill), Proc. biol. Soc. Wash., *23*, 1910: 158 (notes on young; found later to be *pseudoharengus*).

Pomolobus sp., Pearson, Invest. Rep. U. S. Bur. Fish., *1* (10), 1932: 18 (in trawl catch, off Virginia capes).

Doubtful References:

Clupea parvula Mitchill, Rep. in part on Fishes of New York, 1814: 21 (orig. descr.; type local. presumably New York; type lost); Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 452 (descr.).

Clupea virescens De Kay, New York Fauna, Pt. 4, Fishes, 1842: 252, pl. 13, fig. 37 (orig. descr.; type local. New York Bay; type lost).

Clupea pseudoharengus Lönnberg, Ofvers. Svensk. Vet. Akad. Forh., *51* (3), 1894: 114 (observed enter. St. Johns R., Florida in spring; probably *P. aestivalis*).

Pomolobus pseudoharengus Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 55 (St. Johns R., after Bean 1883 and Lönnberg 1894).

Genus *Brevoortia* Gill 1861

Menhaden

Brevoortia Gill, Proc. Acad. nat. Sci. Philad., 1861: 37; genotype by original designation, *Brevoortia menhaden* Gill equals *B. tyrannus* (Latrobe).

Characters. Body oblong, compressed. Bony scutes present, the median line of chest and abdomen with a sharp edge. Scales adherent, the exposed part much deeper than long, the margin serrate or pectinate in adults; a series of modified scales present next to median line on back in front of dorsal fin. Cheek deeper than long. Mouth large. Maxillary extending to or beyond middle of eye. Upper jaw with a distinct median notch. Lower jaw included in the upper one, not projecting, its upper margin (within mouth) nearly straight. Teeth wanting in adults. Lower limb of first Gill arch with an obtuse angle. Gill rakers long and numerous, increasing in number with age, those on upper limb of first arch extending downward and over those on upper part of lower limb. Dorsal with 17–22 rays, the last one not greatly produced; its origin about equidistant between rim of snout and base of caudal. Anal with 17–25 rays, the last one little enlarged. Pelvic small, with 7 rays. Vertebrae about 42–50. Intestine very long. Peritoneum black.

Remarks. The species of this genus generally are recognizable by the strongly serrate or pectinate adherent scales, the exposed part of which is much deeper than long; the modified series of scales next to the median line of the back in front of the dorsal fin; the very long gill rakers on the upper limb, which project downward over the equally long rakers of the lower limb; the very deep cheek; and the rather small pelvic, composed of only seven rays.

The young, about 60 mm TL and less, of North American representatives at least, have minute teeth on the margin of the maxillary, but these disappear with age. The gill rakers on the upper limb do not yet extend downward over those on the lower limb, as in larger fish; the number, as already indicated, increases greatly with age. Furthermore, until the fish reach about 100–125 mm TL, the two series of scales, one on each side of the median line of the back in front of the dorsal fin, do not become fully differentiated or modified. Though the exposed margin of the scales on young may be somewhat uneven, the scales are not definitely serrate; the serrae become somewhat developed when the fish attain a length of about 100 mm and continue development until they are comparatively large, but these serrations are not developed uniformly on all parts of the fish. For some species the length and shape of these serrations or pectinations are diagnostic characters, but fish of nearly equal size must be compared and scales from the same part of the body must be used.

The species of Menhaden included in this work fall into two closely related pairs: *tyrannus* from the Atlantic and *patronus* from the Gulf; *smithi* from the Atlantic and *gunteri* from the Gulf—and one odd species, *brevicaudata*, from Noank, Connecticut, related to *tyrannus*. Such a close relationship between species exists in other groups as well.[36]

In each pair of fishes named, the range probably was once continuous but became discontinuous when the last passageway for marine fishes across the Florida peninsula was closed. At least these fishes do not now occur on the coasts of southern Florida, indicating that suitable conditions do not exist there. Therefore, the separation between Atlantic and Gulf representatives is complete. Under this separation, and apparently under the influence of differences in environment, these fishes have become sufficiently differentiated to constitute distinct species.

Range. The Atlantic and Gulf coasts of the United States northward to Nova Scotia; southern Brazil to Argentina; and western Africa.

Measurements and Counts for Brevoortia. For measurements and counts not discussed below, see p. 258.

HEAD DEPTH: for this genus, measured from the slight crossgroove at occiput to the keel of the first ventral scute. Although this is not an exact vertical, it does provide definite and uniform points for measuring.

SCALES: the number in a lateral series represents the number of oblique series (running upward and slightly backward) across the middle of the side; these should be counted uniformly, since they tend to become reduced in size on the back and larger on the lower part of the side. The comparisons and figures given on these pages are based on scales from the middle of the side below the anterior dorsal rays.

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[36] Among the shad, *Alosa sapidissima* of the Atlantic and *A. alabamae* of the Gulf; also the hickory shad, *Pomolobus mediocris*, of the Atlantic and the skipjack herring, *P. chrysochloris*, of the Gulf and Mississippi Valley. In the family Sciaenidae, the weakfish, *Cynoscion regalis*, of the Atlantic and the sand seatrout, *C. arenarius*, of the Gulf (Ginsburg, *41*: 83); and another pair occurs in the genus *Menticirrhus* (Ginsburg, unpublished).

CAUDAL FIN: lower lobe measured from middle of caudal base.

PECTORAL FIN: axillary appendage measured from base of upper pectoral ray.

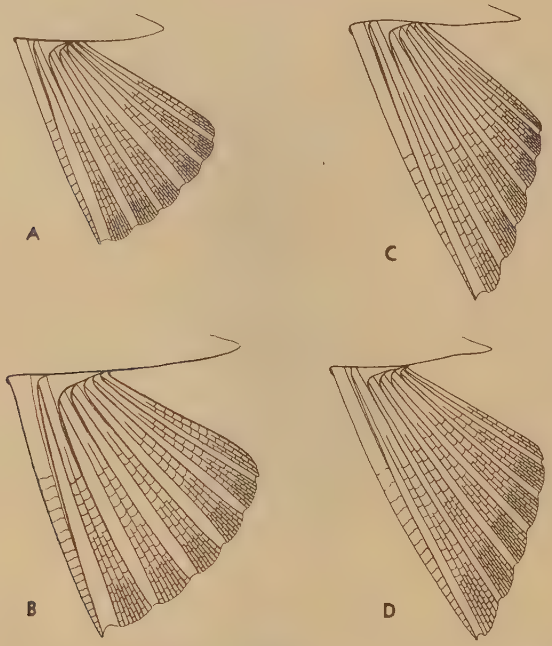

FIGURE 84. *Brevoortia* pelvic fins: A, *patronus*, 215 mm TL, off Galveston, Texas, USNM 129810, see Fig. 91; B, *tyrannus*, 320 mm TL, Chesapeake Bay, USNM 129809, see Fig. 86; C, *gunteri*, 270 mm TL, Rockport, Texas, USNM 129798, see Fig. 93; D, *smithi*, 295 mm TL, USNM 118723, see Fig. 92; all equally enlarged. Drawn by Ann S. Green.

Species. Five species fall within the scope of this work (see Key to Species), and two others, *aurea* and *pectinata*, occur in southern Brazil, Uruguay, and Argentina. Still another one, sometimes identified with *tyrannus*, has been reported for western Africa. I have seen no specimens of the latter and cannot add any information as regards its relationship to American forms. In general, the scales of South American representatives are scarcely reduced in size on the back and on the base of caudal, whereas in North American species they are greatly reduced there.

Key to Species of the Western Atlantic

1a. Scales fairly regularly placed, 35–36 oblique series crossing middle of side; greatest depth of body 30–40 °/₀ of SL.

2a. Scales on back and at base of caudal much smaller than those along middle of side; pelvic fin with a definitely convex margin, the innermost ray more than 67 % of the length of the outermost one, the fin not pointed when folded (Fig. 84 A, B); upper part of opercle with prominent radiating striae; shoulder spot followed by a variable number of smaller dark spots in adults.

3a. Ventral outline of body only moderately convex anteriorly, usually only about half of greatest depth below a straight line extending through lower margin of eye to middle of base of caudal; sheath of scales at base of dorsal fin composed for the most part of a single row of scales covering only the basal third of the longest rays when standing erect; pectoral fin falling far short of base of pelvic fin, 3–7 vertical series of scales between its tip and base of pelvic, the fin with 16–18 (rarely 15) rays.

4a. Maxillary reaching well beyond vertical from posterior margin of pupil, 13–16 % of SL; mandible 16–19 % of SL; pectoral fin failing to reach base of pelvic fin by less than diameter of eye, 3 or 4 vertical rows of scales between tip of pectoral and base of pelvic, its length 17–21 % of SL; caudal fin with lower lobe about as long as head, 25–35.5 % of SL. *tyrannus* (Latrobe) 1802, p. 346.

4b. Maxillary reaching only to a vertical from posterior margin of pupil, 12–13 % of SL; mandible 15.5–16.5 % of SL; pectoral fin failing to reach base of pelvic fin by a distance exceeding diameter of eye, 5–7 vertical series of scales between its tip and base of pelvic, its length 15.5–16 % of SL; caudal fin with lower lobe shorter than head, 22.5–25 % of SL. *brevicaudata* Goode 1879, p. 363.

3b. Ventral outline of body strongly convex anteriorly, much more than half of greatest depth below a straight line extending through lower margin of eye to middle of base of caudal; sheath of scales at base of dorsal fin composed for the most part of two rows of scales covering basal two-thirds of shortest rays when standing erect; pectoral fin often reaching nearly to base of pelvic fin, seldom more than 1 or 2 vertical series of scales between its tip and base of pelvic, the fin with 14–17 (usually 15 or 16) rays. *patronus* Goode 1879, p. 365.

2b. Scales on back and at base of caudal not much smaller than those along middle of side; pelvic fin with a nearly straight oblique margin, the innermost ray not more than 67 % of the length of the outermost one, the fin pointed when folded (Fig. 84 C, D); upper part of opercle with feeble radiating striae, if any; shoulder spot not followed by smaller dark spots.

5a. Scales in only 35–46 oblique series crossing middle of side; five longitudinal rows on side of caudal peduncle; pectoral fin sometimes reaching base of pelvic fin, occasionally falling short of this point by diameter of pupil, its length 17.5–21 % of SL, 0–3 vertical series of scales between its tip and base of pelvic. *pectinata* Jenyns 1842.
Rio Grande of Brazil to Bahia
Blanca, Argentina.

5b. Scales in 48–56 oblique series crossing middle of side: seven longitudinal rows on side of caudal peduncle; pectoral fin failing to reach base of pelvic fin by a space varying from half to a full diameter of eye, its length 16.7–18 % of SL, 3–6 vertical series of scales between its tip and base of pelvic. *aurea* Agassiz 1829.
Bahia (Baía), Brazil, probably to the Rio de la Plata.

1b. Scales small, irregularly placed, about 60–75 oblique series crossing middle of side (difficult to count); greatest depth of body 36–45.5 % of SL.

6a. Length of head 29–31.5 % of SL; maxillary reaching from below middle of eye to vertical from posterior margin of pupil, 2.0–2.4 in head; pectoral fin generally failing to reach base of pelvic fin by somewhat more than half of diameter of eye, 5–8 vertical series of scales between its tip and base of pelvic, its length 18.5–21 % of SL; total number of ventral scutes 30–32 (usually 30); vertebrae 45–47. *smithi* Hildebrand 1941, p. 372.

6b. Length of head 31–35.5 % (usually 32–34 %) of SL; maxillary reaching to, or a little beyond, vertical from posterior margin of pupil, 1.8–2.2 in head; pectoral fin generally failing to reach base of pelvic fin by less than diameter of pupil, 2–4 vertical series of scales between its tip and base of pelvic, its length 19–23.5 % (usually 20–22 %) of SL; total number of ventral scutes 27–30 (usually 28 or 29); vertebrae 42–44.
gunteri Hildebrand 1948, p. 376.

Brevoortia tyrannus (Latrobe) 1802

Atlantic Menhaden, Menhaden, Mossbunker, Bunker, Fatback, Shad, Pogy, Bugfish

Figures 84–89

Study Material. At least 150 specimens, sometimes many more, 70–430 mm TL, 55–355 mm SL, collected at many localities from Massachusetts Bay to Fernandina, Florida. Some of the data used were accumulated by me over a period of 33 years; in addition, unpublished data from Dr. A. Bascom Hardcastle and some gathered by the late William W. Welsh; also juveniles from Woods Hole, Massachusetts; Chesapeake Bay; and Beaufort, North Carolina.

Distinctive Characters. The close relationship of *Brevoortia tyrannus* to *B. patronus* of the Gulf of Mexico is shown in the account of the latter (p. 370). From *B. smithi*, which occupies the same range as the Atlantic Menhaden from North Carolina southward, *tyrannus* differs prominently in having larger scales with notably longer pectinations; these species also differ in several other respects as shown in the account of *B. smithi* (p. 374).

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 150 study specimens, 55–355 mm SL.

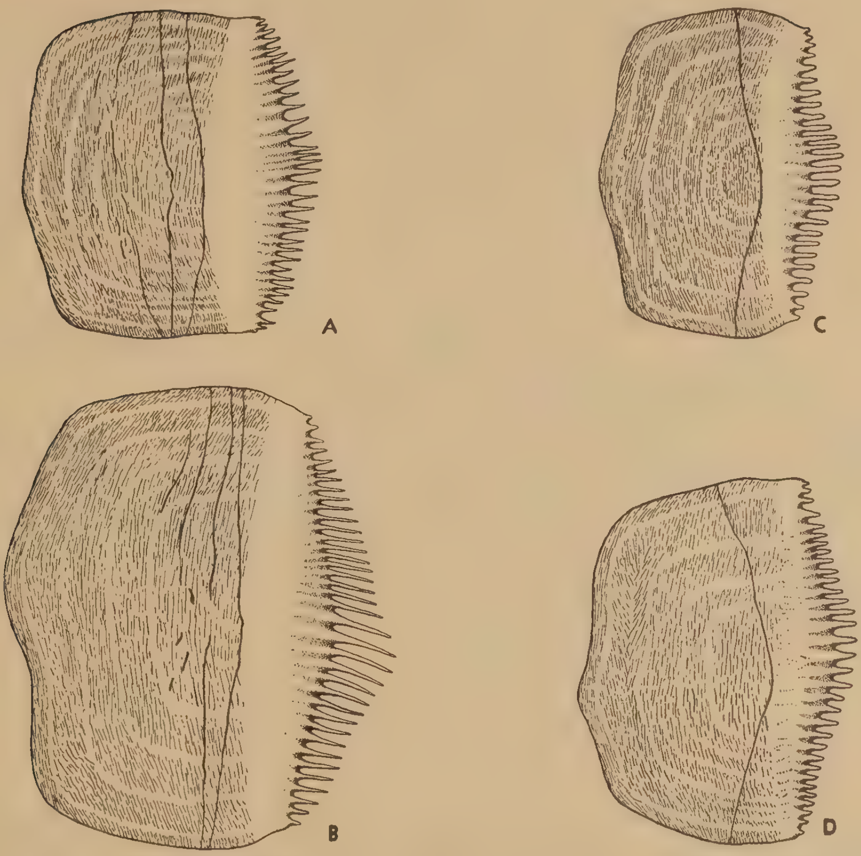

FIGURE 85. *Brevoortia* scales from middle of side below anterior dorsal rays. A, *patronus*, 215 mm TL, see Fig. 91; B, *tyrannus*, 320 mm TL, see Fig. 86; C, *gunteri*, 270 mm TL, see Fig. 93; D, *smithi*, 295 mm TL, see Fig. 92; all equally enlarged.

Body: depth 30–40, usually 32–37.
Caudal peduncle: depth 8.5–11.
Head: length 29–36, most frequently 31–34.
Snout: length 5.5–9.0, usually 6.0–8.0.
Eye: diameter *ca.* 5.0–8.0.
Interorbital: width 6.2–8.2.
Maxillary: length 13–16.
Mandible: length 16–19.
Anal fin: length of base 14–19, usually 15–18.
Pelvic fin: length 8.0–10.
Pectoral fin: length 17–21; usually 18–20.
Scales: oblique series along middle of side, 41–55, most frequently 45–52.
Modified scales: in a series in front of dorsal 31–43, most frequently 33–39.
Ventral scutes: 30–35, usually 32 or 33.
Fin rays: dorsal 18–22, usually 19–21; anal 18–24, usually 20–23; pectoral 16–18, rarely 15.
Vertebrae: 47–49, very rarely 45, 46, or 50 (194 specimens).

Body elongate, compressed, its greatest thickness varying greatly, from nearly half of depth in large fat fish in spawning condition to only about a third of depth in lean half-grown examples; greatest depth generally at, or slightly in advance of, vertical from tip of pectoral, 2.5–3.3 in SL in specimens 100 mm and upward; ventral outline moderately convex anteriorly, usually only half of greatest depth below a straight line through lower margin of eye to middle of base of caudal. Caudal peduncle rather slender, 2.9–4.0, usually 3.2–3.8, in head, and 3.2–4.1, but usually 3.5–4.0, in greatest depth of body.

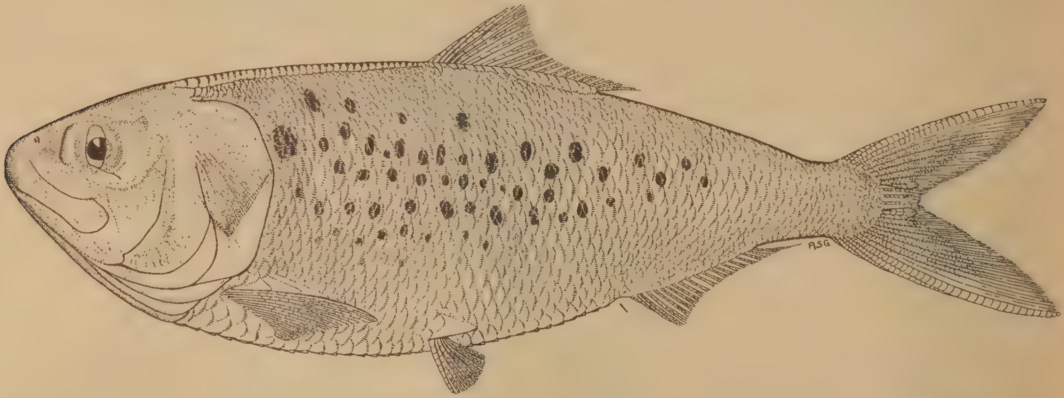

Figure 86. *Brevoortia tyrannus*, 320 mm TL, 247 mm SL, Chesapeake Bay, USNM 129809. Drawn by Ann S. Green.

Scales adherent, the exposed part notably deeper than long, the scale itself somewhat deeper than long (Fig. 85 B); margin irregular in young about 60 mm long; short blunt serrae on margin in examples of about 100 mm, the serrae increasing in length with age, becoming slender hair-like appendages, often extending nearly across the exposed portion of the next scale in large specimens; scales greatly reduced in size on upper part of side, on back, and at base of caudal; in rather regular series on lower half or so of side; most frequently 3 or 4 vertical rows of scales exposed between tip of pectoral and base of pelvic. A row of large modified scales on each side of median line of back in front of dorsal fin, these scales not fully modified in specimens under about 125 mm TL, rather variable in number, most frequently 34–38 in each series. Ventral scutes rather strong, 17–22, usually 18–21, in front of pelvic fins; 10–15, usually 12–14, behind these fins.

Head 2.8–3.5, usually 2.9–3.2, in SL, its depth 3.1–4.0, usually 3.3–3.8. Snout only moderately blunt, with a prominent median notch in adults, the length 3.9–5.5, usually 4.0–4.7, in head. Eye difficult to measure accurately in adults because of much adipose tissue, about 4.4–6.2. Interorbital 4.2–5.3, usually 4.4–5.0. Cheek deeper than long except in young. Maxillary rounded, generally scarcely reaching below posterior rim of eye, the length 1.9–2.7, usually 2.1–2.5, in head. Mandible included in upper jaw, its upper margin (within mouth) nearly straight, its length to joint 1.7–2.0 in head. Upper section of OPERCLE with prominent radiating ridges. GILL RAKERS very numerous; those on upper limb extending down and over those on lower limb, the longest about as long as snout in adults; increasing in number with age and growth, the greatest increase occurring before a 100-mm length is attained: about 60 on lower limb in 60-mm specimens, about 100 in 100-mm fish, about 140 in 200–250-mm examples, and 150–160 in large adults 330–360 mm long. TEETH absent except for minute ones on margin of maxillary in young about 60 mm and less.

DORSAL fin moderately elevated anteriorly, its margin definitely concave, its longest rays as long as snout and fully half of eye, the last ray somewhat longer than the preceding ones; origin of fin generally slightly nearer to base of caudal than to margin of snout; a low sheath on base of fin, composed for the most part of a single series of scales not extending above the basal third of shortest rays when standing erect. CAUDAL rather deeply forked, the middle rays about as long as eye; the lobes rather short, the lower one the longer, about as long as head, 2.8–4.0, usually 3.0–3.8, in SL. ANAL low, little elevated anteriorly, the margin nearly straight; its origin under or somewhat behind vertical from tip of last dorsal ray, its base 5.2–7.0, usually 5.5–6.6, in SL; a very narrow sheath of scales at base. PELVIC fin small, with a very gently convex margin, the outermost ray only a little longer than the innermost (Fig. 84 B), the fin inserted slightly behind vertical from origin of dorsal, the length 3.1–3.8 in head. PECTORAL fin slightly falcate, its length 5.0–5.9 in SL in adults, 1.6–1.9 in head, the longest ray about four times the length of the shortest one, the fin generally failing to reach base of pelvic in adults by a distance somewhat greater than diameter of pupil. AXILLARY APPENDAGE of pectoral variable in length, about 75 % of the length of fin in large examples, only about half of length of fin in examples about 100 mm long, and little developed in young of 50 mm.

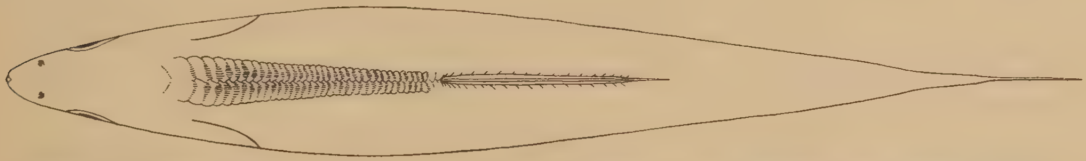

FIGURE 87. *Brevoortia tyrannus*, modified scales in front of dorsal fin, from same specimen shown in Fig. 86. Drawn by Ann S. Green.

Color. In fresh specimens, back dark green to bluish. Sides generally brassy and sides of head bright silvery to slightly brassy. A large black spot at shoulder a very short distance behind margin of opercle and well above middle of side, variable in size and shape among specimens, generally roundish but sometimes vertically elongate, and about as large as pupil. This spot develops first and is generally evident when the fish reach a length of about 75 mm (3 in.). The shoulder spot usually followed among half-grown and large examples, from about 150 mm (6 in.) upward, by a variable

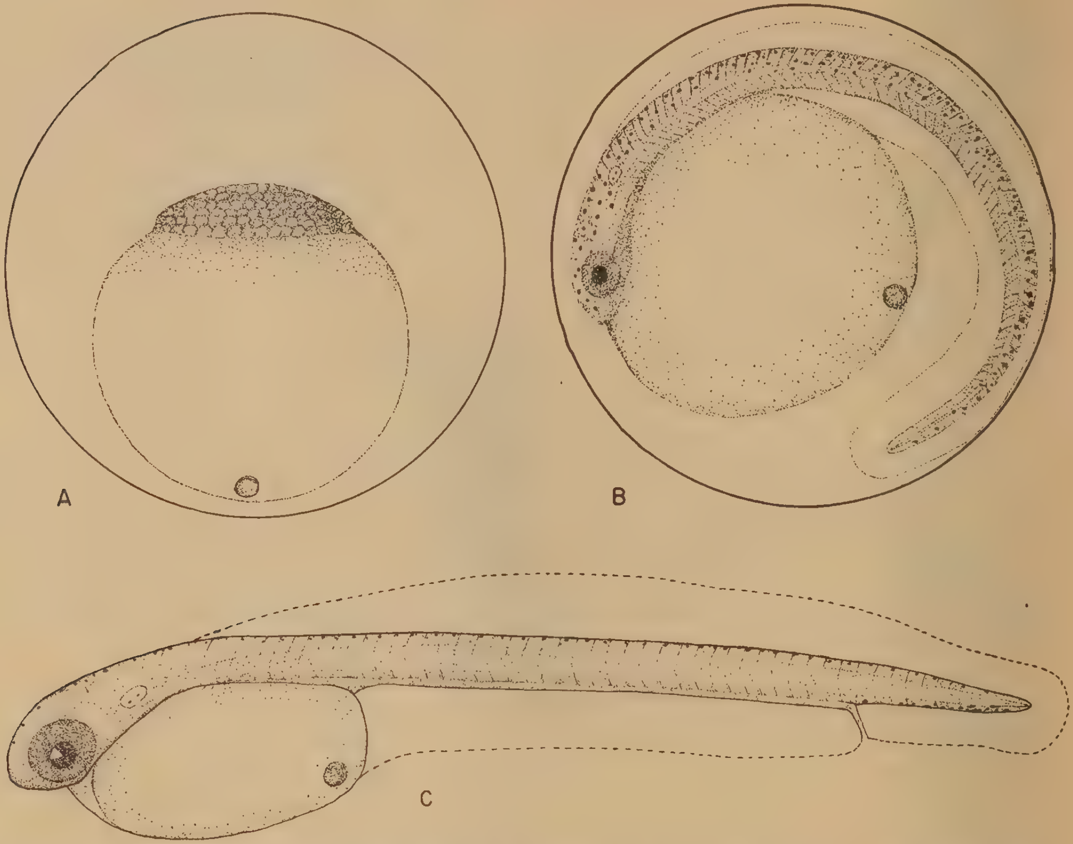

FIGURE 88. *Brevoortia tyrannus.* A, newly laid egg in advanced stage of cleavage; B, egg with advanced stage of embryo; C, newly hatched larva, 4.5 mm long. After Kuntz and Radcliffe.

number of smaller dark spots, sometimes only a few small ones and sometimes many, differing greatly in number, size, and intensity of darkness, these spots sometimes arranged in two, three, or more indefinite horizontal series on anterior part of side, seldom extending far beyond vertical from origin of anal; a profusely spotted example illustrated in Fig. 86. Fins pale yellow to brassy, sometimes with dusky punctulations; caudal generally dusky at base and often with a dusky margin. Peritoneum black.

Variation in color, especially in the dark spots on the side, is very great.

Size. The usual size of adult fish at Beaufort, North Carolina, is about 300–350 mm (12–14 in.) TL. It is generally accepted that the fish grow rather larger in the northern part of the range than in the southern part. The largest specimen in the U. S. National Museum, from Long Branch, New Jersey, is 430 mm (17 in.) long, but a larger one, 480 mm (18 in.), has been reported as taken at Woods Hole, Massachusetts (*120*: 91), and one of 500 mm (20 in.) was reported to the writer by Dr. H. F. Prytherch verbally. The last mentioned specimen was taken at Beaufort, North Carolina, and weighed 3.5 pounds.

Development and Growth. The eggs and larvae have been described by Kuntz and Radcliffe from material collected at Woods Hole, Massachusetts (*76*: 119). The eggs are buoyant and spherical, have a diameter of 1.4–1.6 mm, and are highly transparent; they contain a small oil globule, and are covered with a thin horny membrane; the perivitelline space is broad. Incubation occupied "not more than 48 hours."

The newly hatched fish are "relatively slender" and about 4.5 mm long. The vent, as usual in clupeoid fishes, is "less than one-fifth the length of the body from the posterior end." At four days of age the larvae were 5.7 mm long, and black chromatophores were present in a series along the entire digestive tract. At 9.0 mm the dorsal and caudal fins were at least partly developed, and posteriorly the intestine was convoluted. At 23 mm all the fins had become well differentiated, and the body remained "relatively slender"; black chromatophores were present on the nape, along the margin of the opercle, near the base of the dorsal, anal, and caudal fins, and in groups posterior to the dorsal fin and ventral to the pectoral fin; internal black areas could be seen along the dorsal wall of the abdominal cavity, and a series of dark spots was present above the notochord.

Compared to the Woods Hole larvae, specimens from Beaufort, North Carolina, of comparable size agree with them fairly well in development, but in each phase they are notably more slender. Beaufort examples 9.0 mm long are little compressed and scarcely thicker than a number-60 sewing thread; the depth is contained about 30 times in TL. Specimens 18 mm long are fully as well developed as those of 23 mm described and illustrated by Kuntz and Radcliffe, and the 23-mm examples are rather more advanced than the northern ones of equal length; the body continues to be more slender; the depth is contained about 21 times in TL. In 25-mm preserved examples from Beaufort, the convoluted intestine noted in younger fish is scarcely discernible, and the vent is now situated slightly behind a vertical from the base of the last dorsal ray, about as in the adult. Some examples, at a length of 30 mm, or even up to 35 mm, remain very slender, their depth being contained about 13 times in TL; and in these slender examples the ventral surface of the chest and abdomen remains round to slightly flat, with indications of a row of bony points along each lateral edge. Juvenile pigment spots remain about as described for examples of 23 mm or so, but other specimens of the same length are much more compressed and notably deeper; their greatest depth is contained only about 7.7 times in TL, or only about 6.7 in SL. In these deeper and older fish, the two series of lateral bony points noted in the slender fish have become coalesced to form definite ventral scutes on the median line of the chest and abdomen; also, the fish are rather fully pigmented, the sides of the head are bright silvery, a silvery lateral band is evident, and a sheen of the same color is present on the sides of the abdomen. It seems, then, that when the fish reach a length of about 30 mm the increase in length is retarded during metamorphosis from the somewhat roundish slender larvae to the deeper and more compressed young adults.

Schools of young Atlantic Menhaden were observed repeatedly at Beaufort in winter and spring, and specimens 24–35 mm, caught from a school on April 23,

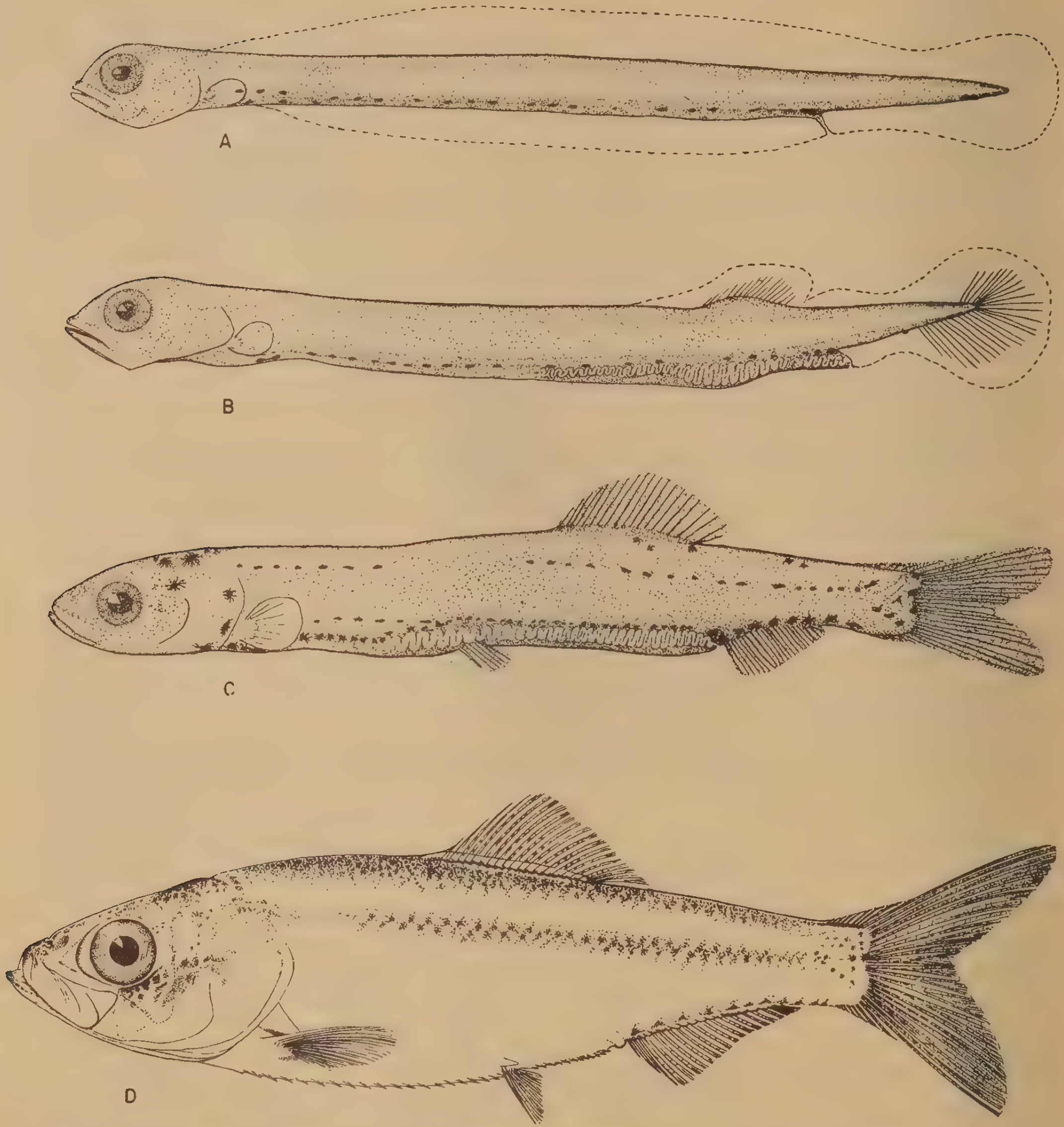

Figure 89. *Brevoortia tyrannus.* A, larva four days after hatching, 5.7 mm; B, young, 9 mm; C, 23 mm; D, 33 mm. A, B, C drawn by Albert Kuntz, D by E. B. Decker.

1926, differed little in development; all had remained slender and were more or less in the larval stage. As seen in the water they were almost transparent, but when removed from the water, dark pigment spots were evident along the middle of the side in a more or less definite lateral band.

Specimens 40–45 mm long are shaped very much like large fish, although they remain rather more slender; their greatest depth of body is contained about 3.6–4.0 in

SL. The obtuse angle in the lower limb of the first gill arch is evident, and the gill rakers on the upper limb of this arch now definitely extend down and over the upper ones on the lower limb. Striations on the upper plate of the gill covers are evident, but the cheek remains about as long as deep. Scalation is about complete. The silvery lateral band of smaller specimens has blended with the silvery abdomen; the dark shoulder spot, always present in adults, is evident though small; and in some specimens suggestions of supplementary spots are already present.

The gill rakers increase in number and in proportionate length with age (see *Description*). Therefore, if their number is to be usable at all for differentiating species, specimens of equal size must be compared.

In the Gulf of Maine, the fish hatched during the summer reach a length of 60–80 mm during their first winter and average slightly more than 160 mm the second winter, and those hatched in the fall are 30 mm long the first winter and 130 mm the second winter, with every gradation in size between the two (*16*: 122).

In Chesapeake Bay, where the fish apparently spawn only during the autumn, the young are only about 27 mm long the following January and 46 mm the following April (*59*: 103). These data, though not complete, are in general agreement with more extensive data collected by me at Beaufort, where spawning quite certainly occurs only during late fall and early winter. Seventy-nine larvae, collected there from the last half of November to and including the first half of March, were between 4.0–20 mm, and the average increase in length in each month was about 12 mm, excluding December, when only three larvae were taken (5.0, 5.0, and 7.0 mm). Thereafter, more rapid growth was indicated: seven specimens taken the last half of March were between 22–31 mm and averaged 27 mm; 110 collected in April were 30–40 mm and averaged about 35 mm; 50 collected during May were 30–41 mm and averaged about 35 mm; and 48 examples taken in June ranged between 38–56 mm and had an average length of 45 mm. Lengths of 85–150 mm (3.4–6.0 in.) were attained during their second winter; the average was about 110 mm (4.4 in.); measurements were based on 167 fresh examples.

"Sexual maturity is apparently attained in the season following the third winter, and a few of the older fish Welsh examined showed as many as 9–10 winter rings on their scales" (Bigelow and Schroeder, *15*: 116).

Spawning. The Atlantic Menhaden spawn at sea in saline waters. Many large fat fish with well-developed roe were observed by me off Beaufort, North Carolina, during autumn only. Such fish were seen also in the fall in the Chesapeake Bay area (*59*: 103) and in December off Fernandina, Florida (from unpublished notes by William W. Welsh). However, off New England, spawning takes place in late spring and throughout the summer, the height of the spawning season occurring in June; and in 1915 off Woods Hole, Massachusetts, eggs were taken as late as the last week of October (*76*: 119).

At Beaufort, spawning apparently takes place only off Beaufort Inlet, for all of the small ones, 16 mm and less, were taken at sea. This would be expected, for the large mature fish in that vicinity seldom enter the harbor or other inshore waters. Northward, however, as at Woods Hole, Massachusetts, the eggs and larvae were collected in the harbor (*76*: 119). The place and season of spawning, then, seem to vary according to locality.

Habits. Both young and adults, acccording to Bigelow and Schroeder, feed and travel in compact schools at the surface, swimming close together side by side and tier above tier (*15*: 114):

> In calm weather they often come to the surface when their identity can be recognized by the ripple they make, for pogies, like herring, make a much more compact disturbance than mackerel do... Also, pogies as they feed frequently lift their snouts out of water, which we have never seen herring do, while they break the water with their dorsal fins, also with their tails. And the brassy hue of their sides catches the eye.

The larvae appear to be more or less solitary, for only one specimen or at most a few were generally taken in a haul, off Beaufort. They do not stay at or near the surface as strictly as older ones do, for most of the larvae at hand were taken in nets towed along the bottom. However, schooling and surface swimming begin early in life, for many schools of young 25–35 mm long (some just reaching the adult stage) were observed many times on windy days near shore on the leeward side of Pivers Island at Beaufort.

Migrations. These fish are present principally in the Gulf of Maine from July to September, off Woods Hole, Massachusetts, from June to September, and off the coasts of New York, New Jersey, and Delaware from May to September, being most numerous during midsummer; in Chesapeake Bay small to medium-sized fish are numerous throughout the summer, and large ones are taken off the mouth of the Bay (or off the Capes) during October and November; in North Carolina, small and medium-sized fish are present all summer, the large ones from October to December; and on the east coast of Florida the fish are numerous from early spring to late fall.

Small to medium-sized specimens are present in Chesapeake Bay throughout the year but in greatly reduced numbers during the winter. Adults off Beaufort, though most numerous during late fall, sometimes remain in the nearby offshore waters until January if the winter is mild. Schools composed of fish that are generally 150 mm (6 in.) and less are present in Beaufort Harbor and connecting estuaries all winter, and schools of young, generally under 50 mm in length, ascend freshwater creeks or enter small drainage ditches in the spring. Unlike adults in northern waters that come close inshore, into the bays and harbors (*16*: 122), large fish in North Carolina very rarely cross Beaufort Inlet to enter the Harbor and adjacent waters.

It is still much of a mystery where the schools of adults go after the fish leave the waters within 10–15 miles of shore, the usual operating range of the fishing schooners. Sufficient taxonomic work has been done, however, to indicate that each section of the coast, that is the New England, Middle Atlantic, and South Atlantic states, has a more or less distinct population. Therefore, if a north-south migration does take place, then the fish from each section return to the general vicinity from which they migrated originally. It seems more probable now that the principal migration is offshore and inshore.[37] No doubt temperature is an important factor in the movements of the fish; it certainly affects the supply of plankton upon which they feed. In years when inshore runs fail, it is even probable that the fish remain so far offshore that they are beyond the usual range of the fishing vessels. In slight confirmation of this theory, I recall that one autumn, when the usual inshore runs failed at Beaufort, a progressive operator, upon my suggestion, induced one of his boat captains to go farther offshore than usual in search of a catch. Fish, indeed, were found, at a considerable distance offshore, apparently too far off for practical fishing with the crews and schooners available.

Food. Menhaden feed on small organisms strained from the water by their numerous long, slender, close-set gill rakers, which form an effective strainer. While feeding, the fish generally swim near the surface and often "break water"; they whirl around, sound a short distance, come out of the whirl, and swim up and straight ahead at a considerable speed for a rather short distance. During this time the mouth is wide open and the gill covers are lifted, thus making it possible for a fish to filter a great amount of water with minimum effort. The food that is ingested depends in large measure upon the organisms that are present where the fish are feeding. Even a considerable amount of mud and general debris is often swallowed. Included in the stomach contents examined by various investigators were: numerous small crustaceans, especially copepods; small annelid worms; rotifers; and unicellular plants, particularly diatoms and peridinians. The plant organisms, as a rule, constitute the chief food.

This species has a very thick-walled stomach, and a long intestine, as is usual among fish that feed on vegetable matter. Among 64 fish taken at Beaufort, ranging between 65–214 mm, the intestinal tract increased more or less proportionately with the length of the fish; generally it remained between 400 and 450 % of the standard length, according to A. Bascom Hardcastle (unpublished data).

Enemies. Most predatory animals associated with the sea feed on Atlantic Menhaden—an easy prey because of their habit of schooling. Their fiercest enemy probably is the bluefish (*Pomatomus*), which, it is said, kills many more than it eats. Among the other fish that feed on them extensively are the cod, pollock, hakes, weakfish, swordfish, tuna, dolphin, amberjacks, and sharks. Whales and porpoises, as well as birds, also devour many of them.

Parasites. Atlantic Menhaden so often have a large crustacean parasite in the mouth that they are sometimes referred to as "bugfish." It is said that in some schools nearly every fish has a parasite in its mouth. This "bug," an isopod listed as *Olencira praegustator* (Latrobe) (*107*: 231), has a robust body, generally fully half an inch long and occasionally approaching an inch in length. Sometimes the mouth of the fish is deformed because of its presence; thus the amount of water screened for food must be considerably reduced in fish so infected.

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37. According to Rose (*110*: 104, 105), the recent investigations by the U. S. Fish and Wildlife Service make it likely that the north-south migrations of the Menhaden are more regular and extensive than Dr. Hildebrand supposed. —H. B. B.

Another large parasite, the copepod *Lernaeenicus radiatus* (LeSueur), buries its horns in the flesh on various parts of the fish's body, most commonly along the back (*137*: 480). This parasite sometimes approaches a length of two inches and has a predominant reddish color, which makes it very conspicuous. Other copepods listed by Wilson as parasitic on *B. tyrannus* are: *Bomolochus teres* Wilson, *Caligus schistonyx* Wilson, *Caligus chelifer* Wilson, *Pandarus sinuatus* Say, *Lernanthropus brevoortiae* Rathbun, and *Clavellisa spinosa* Wilson.

The following have been listed by Linton (*85*: 440): *Scolex polymorphus* Dujardin, a cestode, small and free in the intestine; cysts and blastocysts of *Synbothrium* on the viscera; and the trematodes *Distomum appendiculatum* Rudolphi and *D. vitellosum* Linton; later he added *Dactylocotyle* sp., and *Distomum pyriforme* Linton (*86*: 352).

Hardcastle has reported a sporozoan parasite of the genus *Eimeria* for the testes of specimens taken at Beaufort; he stated that a "study of over a hundred individuals [Menhaden] showed an infection of nearly 50 per cent" (*54*: 214).

Diseases. No report of a specific disease has been found in the literature, but there are records of many fish having become stranded along the shore. It has been suggested that their enemies at times drive them ashore, but my observation is that the fish make no special effort to flee from enemies. In fact, when caught in a net they make little effort to escape. It seems more probable, therefore, that the stranded fish died of a disease. An epidemic has indeed been reported (*123*: 742).

Variations. Large fish generally are proportionately deeper than small ones, and those from the southern part of the range are proportionately deeper than northern ones. However, the variation in depth among fish from any one general region is great enough to obscure any definite distinctions. Southern fish have a somewhat larger head and longer fins (especially the pectoral) than those from the northern part of the range, but the gap is fully bridged by examples from intermediate areas. Contrary to expectation, data at hand show that the vertebrae do not average fewer in southern specimens. But further detailed studies are needed to determine the exact characteristics of populations inhabiting the different general sections of the coast; even now specimens from the Gulf of Maine are too few in the collections at hand to determine their finer characteristics.

As shown in the *Description*, the number of gill rakers increases greatly with age, with the principal increase occurring before the fish reach a length of about 100 mm (4 in.). Also, the scales in small specimens have only irregular margins while those in larger fish are pectinate. In using scales to differentiate species (their development in all species being similar), it is necessary to compare scales from examples of about equal size; and it is preferable to use large specimens, for in them the differences are most pronounced.

See *Color* for variations in color.

Commercial Importance. These fish, though exceedingly valuable, are not used very extensively as food by man, mainly because of their bony nature and oiliness. However, some find the flesh delicious, and those living along the coast, especially the fishermen, eat them in season as a common article of diet. Considerable quantities are often "corned" (salted) for home use during winter, and the writer knows from first-hand experience that these fish are delicious when smoked. They were canned to a limited extent for export during the last war, and a small quantity is still canned for home consumption.

Because of their abundance, large numbers are available for reduction to oil, fish meal, and fish scrap; the Atlantic Menhaden fishery is one of the most valuable of our fish industries. The catch for 1945 amounted to 759,073,820 pounds, valued at $ 11,202,127 (Canned Fish and Byproducts, U. S. Fish Wildl. Serv., 1945: 15); of this amount, 120,493,920 pounds were credited to Florida, 142,209,510 to North Carolina, 77,232,910 to Virginia, 280,463,340 to Delaware, and 138,584,140 to New Jersey. For 1950 through 1953, the approximate catches have been as follows: between 9,304,000 and 39,900,000 pounds for New England, mostly taken south and west of Cape Cod; between 372,950,000 and 857,584,000 pounds for the Middle Atlantic states; 92,374,000 for Chesapeake Bay; and between 147,125,000 and 314,841,000 pounds for the South Atlantic states. In 1953 the total catch was 1,259,031,000 pounds.

Because of the great fluctuations in catch from year to year, the catch for a single year, or even for many successive years, may not indicate their actual abundance. Furthermore, since the fish are not equally fat every year, or at all times when available, equal quantities of fish (pounds) do not always yield equal quantities of oil (gallons), the most valuable product obtained from these fish. Thus the value of a given catch depends to a large extent upon the amount of oil it yields. In general, large fish yield more oil than small ones. For example, at Beaufort, North Carolina, the summer "runs," consisting of small to medium-sized fish, yield so little oil that they are considered scarcely worth handling, but the fall runs, consisting of large and fat gravid fish, make the industry profitable.

In discussing this subject, Greer (*48*: 24)[38] wrote as follows in 1915:

> The yield of oil varies greatly on different parts of the coast, and also from year to year and at different seasons. The fish are always larger and fatter during the fall than at any other season, consequently there is a greater yield of oil during that period. The fish taken from northern waters produce more than those taken from southern waters; the writer visited one of the northern factories during August 1913, and was told that a short time previous to his visit they had made 20 gallons, and that the average yield for July had been 16.5 gallons per 1,000 fish.[39] The maximum for the Middle Atlantic States is about 15 gallons, though it usually is less; in the early part of the season it is very much less than that amount. The South Atlantic fish rarely produce more than 8 gallons per 1,000 fish, and frequently it is less than 1 gallon during the early spring fishing. The average number of gallons of oil made from 1,000 fish during the season of 1912 was as follows: Connecticut 11.73; New York 11.36; New Jersey 5.08; Delaware 7.72; Virginia 3.72; and North Carolina 1.98.

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[38] This paper, entitled "The Menhaden Industry on the Atlantic Coast," although written before the manufacture of fish meal for stock and poultry feed, contains much valuable information concerning the history of the industry, the construction of factories, the machinery used in these reduction plants, the vessels employed, the methods of fishing, their reduction, men employed, etc.

[39] The fish generally are measured, and the measure used is said to contain 1,000 fish, no account being taken of the size of fish. Thus, the measure arbitrarily contains 1,000 fish regardless of whether they are 6 or 12 inches long. In converting the number of fish to pounds, the factor 0.67 is used in the statistical division of the U. S. Fish and Wildlife Service. That is, the number of fish is multiplied by 0.67.

As further evidence of the great value of this extensive fishery, additional data from Greer show that the total catch for 1912, a near banner year, was 1,061,483,750 fish (711,435,312 pounds); this catch yielded 6,651,203 gallons of oil valued at $ 1,551,990 and 88,520 tons of scrap worth $ 2,138,165; 48 factories, valued at $ 3,625,983, were in operation; the vessels engaged in the fishery numbered 147, valued at $ 3,456,792; and there were 2,159 employees in the factories and 3,735 fishermen, drawing a combined wage of $ 1,579,984.

The value of the fish scrap, now that most of it is used as fish meal for poultry and livestock feed instead of as fertilizer, is considerably greater than it was; this change in turn produced other changes, for this processing requires quicker and more sanitary handling of the fish, including cooking before decomposition sets in; some changes at the factories were also required, for apparatus had to be installed for drying the residue quickly after the oil had been extracted.

Fluctuations in Abundance. No species has been more erratic in its appearances along the coast than *B. tyrannus.* For example, in 1911 and in 1912 large catches were made at Beaufort, the center of this fluctuating industry in North Carolina, but then these near banner years were followed by several exceptionally lean years, which forced some of the local operators into bankruptcy. However, in 1918 the fish were back again. Even though the annual catches (without adjustment for variations in fishing effort) have fluctuated since that time from 54,476,000 pounds in 1932 to 181,968,000 pounds in 1939, there has been no complete failure in any year since the period 1913–1916.

Although at least some of the reasons for the fluctuations in abundance of certain species of fish are known, no explanations have been given for the fluctuations in Atlantic Menhaden. For the Gulf of Maine, Bigelow and others have stated that these fluctuations date back to the early history of the fishery and have continued since then (*15*: 116, 117; *16*: 120). Thus, in 1845 they were abundant and in 1847 scarce. Then, for some years prior to 1875, they were tremendously abundant off the coasts of Massachusetts and Maine every summer, and a considerable fishery for them grew up on the Maine coast. However, during the cold summer of 1877 few were taken in the Gulf until September and October, when they were reported as "about as abundant as normal." So few of these fish appeared north of Cape Cod from 1879 through 1885 that the capture of one caused comment, and many people thought that the fish would never return. However, in 1886 the fish reappeared and in 1888 they were so abundant that the fishery was revived. The period of abundance was short, however, for in 1891 the catch was less than half of that taken the year before, and in 1892 few were seen north of Cape Cod. Similar periods of scarcity and abundance followed each other until 1904, when a 20-year period of scarcity began. Then in 1922 the fish returned in such abundance that 18 steamers fished successfully in Massachusetts Bay; further, "upward of 1,500,000 pounds were landed by the larger fishing vessels besides what the small boats brought in." From the middle 1920's until the middle 1940's there were not enough of them in the Gulf of Maine to be of any commercial importance there.

Although they were plentiful again in the Gulf from 1946 through 1949, fewer were present from 1950 through 1956.

Comparison of statistics for the past 20 years or so shows no correlation as to the quantity taken along different sections of the coast. If North Carolina, for example, has a good run in a given year, it does not follow that Florida, New York, or New Jersey will have a good run that same year. For example, in 1929 the fishery in North Carolina yielded 173,490,000 pounds of Atlantic Menhaden—considered an unusually large catch. But in that same year the catch credited to Florida was rather less than average, 50,532,000 pounds, and the combined catch for New York and New Jersey was a near failure with only 11,092,000 pounds. Again in 1937, when the catch in North Carolina amounted to only 61,706,000 pounds (next to the smallest during about 20 years), the catch for Florida was 139,788,000 pounds and the combined catch for New York and New Jersey was 99,684,000 pounds, both well above the average for the 20-year period.

It seems improbable that the commercial catches taken by the fisheries in the western Atlantic have made any serious inroads on Atlantic Menhaden populations in any general area. If it is true that the handiwork of man has had no important effect on the abundance of this species, then the fluctuations must be attributed to natural phenomena that occur in their enviroment.

Successful and unsuccessful spawning seasons are known to profoundly affect the abundance of some species and this is probably so in the case of this species also. However, it does not explain why a fish that may attain an age of 9–10 years (as concluded from the number of winter rings on the scales) may be abundant one year in a certain locality but very scarce or even absent there the next year. Furthermore, since the fish caught during a fishing season in any one area are not all of the same age and size, the failure of one or even several successive spawning seasons would not cause an abrupt diminution from one year to the next. The theory that these fish follow their food and therefore remain in water having an abundant growth of plankton of suitable size has been advanced. It would follow then that if sufficient food is not available near the shore, the fish will remain offshore, perhaps beyond the range of the vessels employed in the fishery. This theory seems to be the most plausible one advanced to date. It has been suggested also that the temperature of the water is a factor, which no doubt is true, particularly insofar as it affects the growth of the planktonic food required by these fish. It is obvious that further study is needed to determine more specifically the reason or reasons for the exceedingly great fluctuations in the runs of Atlantic Menhaden.

Methods of Fishing. These fish are caught chiefly with purse seines, though smaller quantities are taken with long haul seines and in pound nets; and minor quantities are caught with ordinary seines or drag nets and with gill nets.

The vessels employed in the operation of this large industry are a very familiar sight to those living near the fishing centers, and in some localities, for example Beaufort and Moorehead City, North Carolina, the economic life of the communities is so dependent upon the fishery that nearly everyone watches the incoming vessels to see what kind of a catch has been made. If the catch is good, the operator's flag is flown from the "crow's nest" (see below), thus notifying the factory to get up steam and for hands to stand by to take care of the catch. It is a common saying among people of these communities that the stench from the factories "smells like bread and butter" to them.

Formerly, sailing vessels were used in this fishery. These were superseded by auxiliary schooners, which in turn were replaced by power-driven vessels equipped with diesel engines. All of those used in North Carolina and southward are of nearly the same design and are capable of carrying 400,000 fish or more. They are ruggedly built wooden vessels, most of them less than 100 feet long, with a broad beam and a high bow to make them seaworthy. A tall mast is set in the forepart of the vessel, and near the top of it is a small platform, generally surrounded by a rail and often partly enclosed by canvas. This is the crow's nest from which one or two men watch for schools of fish.

Each vessel carries two "purse seine boats" which, when not in use, are suspended from derricks on each side of the mother ship. When a school of fish is sighted, the vessel approaches it, the purse seine boats with seine aboard are lowered, and the school of fish, or at least part of it, is surrounded as quickly as possible with the seine. Next the seine is "pursed" by drawing in a line (at the bottom of the net) that runs through rings. After the fish have been concentrated into a more or less compact mass they are loaded aboard the vessel with a large dip net, generally operated by means of block and tackle.

Steamers are also used in pursuing these fish, though less so than formerly. They are larger than the vessels driven by diesel engine, hence they can go farther and stay out longer. This was advantageous in former days when the scrap was used only as a fertilizer, but now that it is used mostly as poultry and stock feed and since the fish preferably should be processed on the day they are caught, the advantage of these larger vessels has diminished.

General Range. Continental waters of North America, from Nova Scotia to Florida; taken commercially from eastern Maine to northern Florida, as far south as Mayport. Stragglers have been taken as far northeastward as St. John Harbor, New Brunswick (*64*: 11), and St. Mary Bay, Nova Scotia (*16*: 120), and as far south as Indian River City, Florida (*33*: 56); and large schools have been reported as seen during the winter off Cape Canaveral and Mosquito Inlet (*43*: 36). This species has often been reported for the coasts of the Gulf of Mexico, Brazil, Uruguay, and Argentina, but these reports are for another species (p. 344; *58*: 1–39). Fowler reported it for the "Senegal region" of Africa but had no specimens from there (*39*: 174); also, there are earlier reports of a *Brevoortia* from Africa; whether it is *tyrannus* needs verification.

Details of Occurrence. As discussed under *Fluctuations in Abundance* (p. 358), it is well known that Atlantic Menhaden fluctuate widely from year to year and over periods of years. Prior to 1850 they were reported as plentiful at the mouth of the

Bay of Fundy on the New Brunswick side; though they have not frequented these waters subsequently, except for occasional strays (see above), they have been plentiful off and on westward. In years when these fish were plentiful, their chief centers of abundance north of Cape Cod have been the Massachusetts Bay region, the region of Casco Bay, and among the islands thence eastward to Penobscot Bay, where they may congregate as much as 40–50 miles out from the land. But they have never been reported for the central part of the Gulf or for the off-lying fishing banks.

Although the Atlantic Menhaden's appearances and disappearances are unpredictable for any given locality, they are far more regularly and uniformly numerous southward from Cape Cod than northward, not only along the open coast but within the larger bays and sounds as well. Landings southward from New York for 1954, the most recent year for which pertinent catch statistics are at hand, were as follows: 136 million pounds for New York and New Jersey, 306 million for Delaware, 160 million for North Carolina, 42 million for northeastern Florida, but only four million pounds for Maryland and Virginia combined, and about the same amount for South Carolina. While these data might suggest centers of greatest abundance at some areas along the American coast compared to others, it seems more likely that they reflect not only the economic laws of supply and demand, but the wide and varied patterns of distribution that have been discussed under *Fluctuations in Abundance* (p. 358).

Synonyms and References:

Clupea tyrannus Latrobe, Trans. Amer. philos. Soc., *5*, 1802: 77, pl. 1 (drawn without dorsal; no descr.; type local. Chesapeake Bay; notes probably applicable to some species of *Pomolobus*; an isopod, *Olencira praegustator*, from mouth descr.).

Clupea menhaden Mitchill, Rep. in part on Fishes of New York, 1814: 21 (orig. descr.; type local. presumably New York); Mitchill, Trans. Lit. philos. Soc. N. Y., *1*, 1815: 453 (descr.; New York; use as fertilizer); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 436 (synon., descr.).

Clupea neglecta Rafinesque, Amer. Month. Mag., *2* (3), 1818: 206 (orig. descr.; type local. Long Island, New York).

Alosa menhaden De Kay, New York Fauna, Pt. 4: Fishes, 1842: 259, pl. 21, fig. 60 (descr., import., New York); Storer, Fishes Mass., 1867: 158, pl. 26, fig. 4 (descr., abund., how caught, uses, Massachusetts Bay).

Alosa sadina De Kay (not of Mitchill), New York Fauna, Pt. 4: Fishes, 1842: 263, pl. 40, fig. 129 (descr., fig. clearly shows *B. tyrannus*).

Clupea carolinensis Gronow *in* Gray, Cat. Fish. Brit. Mus., 1854: 140 (orig. descr.; type local. S. Carolina).

Brevoortia menhaden Gill, Rep. U. S. Comm. Fish. (1871–1872), 1873: 811 (how and where used, range); Uhler and Lugger, Rept. Comm. Fish. Md., ed. 1, 1876: 156; ed. 2, 1876: 133 (descr., synon., use, Maryland).

Brevoortia tyrannus Goode, Proc. U. S. nat. Mus., *1*, 1879: 5 (establ. validity of Latrobe's specific name, *tyrannus*), 31 (descr.; cf. "var. *aurea*" and *B. patronus*; varieties *menhaden* and *aurea* reognized; new variety *brevicaudata* named and defined); Goode, Rep. U. S. Comm. Fish. (1877), 1879: iii–xii, 1–529, pls. 1–31 (complete hist. of American menhaden; discus. species and varieties, includ. S. American ones; full descr. of industry); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1882: 269 (descr., synon.); Good *in* Goode, *et al.*, Fish. Fish. Industr. U. S., 1 (3), 1884: 569, pl. 205 (common names, migr., distr., food, reprod., enemies, uses); Goode, Amer. Fishes, 1888: 385, fig. (migr., food, etc.); Smith, Bull. U. S. Fish Comm. (1890), *10*, 1892: 64 (behavior in lower Potomac R.); Smith, Bull. U. S. Fish Comm. (1891), *11*, 1893: 191, 195 (small ones enter brackish and fresh water); Peck, Bull. U. S. Fish Comm. (1893), *13*, 1894: 113–126, pls. 1–8 (food and feed.); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 433, fig. 195 (descr., size, range, synon.); Evermann and Kendall, Rep. U. S. Comm.

Fish. (1899), 1900: 56 (refs.); Linton, Bull. U. S. Fish Comm. (1899), *19*, 1901: 277, 440 (food, cestode and trematode parasites); Bean, T. H., 7th Rep. Forest Comm. N. Y. (1901), 1902: 309, fig. (synon., local names, size, range, commerc. uses, migr.); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 211 (synon., descr., size, range, uses, New York); Linton, Bull. U. S. Bur. Fish. (1904), *24*, 1905: 352 (nematode, trematode, and copepod parasites); Richardson, Bull. U. S. nat. Mus., 54, 1905: 231 (isopod parasite); Fowler, Rep. N. J. St. Mus. (1905), 1906: 103, pl. 6 (descr., New Jersey); Smith, N. C. geol. econ. Surv., *2*, 1907: 130, figs. 44, 45 (diagn., range, size, common names, spawn., econ. import., North Carolina); Kendall, Occ. Pap. Boston Soc. nat. Hist., *7*, 1908: 40 (refs., New England); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31*, 1913: 742 (reprod., food, parasites, epidemic, Woods Hole, Massachusetts); Regan (in part of Latrobe), Ann. Mag. nat. Hist., (8) *19*, 1917: 301 (*B. patronus* and *B. aurea* in synon., diagn., range); Kuntz and Radcliffe, Bull. U. S. Bur. Fish. (1915–1916), *35*, 1918: 119–123, figs. 76–86 (eggs, larval develop.); Hildebrand, Rep. U. S. Comm. Fish. (1918), Append. 6, 1919: 3, 2 figs., 1 pl. (photos of scales, descr., uses, spawn., food, Beaufort, North Carolina); Huntsman, Contr. Canad. Biol. (1921), 1922: 11 (St. John Harbor, New Brunswick); Bigelow and Welsh, Bull. U. S. Bur. Fish. (1924), *40* (1), 1925: 118, fig. 48 (descr., size, range, breed., food, enemies, commerc. import., Gulf of Maine); Jordan, Fishes, 1925: 277, fig. 211 (econ. import., habitat); Fish, Bull. U. S. Bur. Fish (1925), 1926: 165–167, 170, 172 (surface catches, Woods Hole, Massachusetts); Nichols and Breder, Zoologica, N. Y., *9* (1), 1927: 41, fig. (distr., food, life hist., size, New York and s. New England); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43*, 1928: 102, figs. 55–59 (refs., descr., var., food, spawn., econ. import., range, Chesapeake Bay); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 4 (diagn., range, uses, food); Truitt, Bean, and Fowler, Bull. Md. Conserv. Dep., 3, 1929: 51, fig. 17 (descr., Maryland); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 69, fig. (range, uses, spawn., habits, "races"); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 44 (range, synon.); Wilson, Bull. U. S. nat. Mus., 158, 1932: 381, 401, 404, 437, 451, 480 and 517 (copepod parasites); Greeley, 26th Rep. N. Y. Conserv. Dep. (1936), Suppl., 11, 1937: 91 (brackish water Hudson R.; numerous at mouth of Mamaroneck R.); Perlmutter, 28th Rep. N. Y. Conserv. Dep. (1938), Suppl., 15 (2), 1939: 17, tab. 4 and 15 (time of occur., Long Island; spawn.); Greeley, 28th Rep. N. Y. Conserv. Dep., Suppl., 15 (2), 1939: 82 (young at Long Island, New York; prey of other fish); Anonymous, Fish. Resourc., U. S. Senate Doc. 51, 1945: 71, figs. (habits, biol., econ. import.); Hildebrand, Smithson. misc. Coll., *107* (18), 1948: 7, fig. 1 (synon., relation., descr., var., range); Bigelow and Schroeder, Fish. Bull. (74) U. S. Fish Wildl. Serv., *53*, 1953: 113 (descr., life hist., Gulf of Maine).

Brevoortia tyrannus Fowler, Monogr. Acad. nat. Sci. Philad., 7, 1945: 45, 74, 165 and 266 (refs., occur.).

Menhaden, Greer, Rep. U. S. Comm. Fish. (1914), 1915: 5–27, pls. 1–7 (complete acct. of industry); Hardcastle, J. E. Mitchell Sci. Soc., *57* (2), 1941: 214 (sporozoan parasite); Anonymous, Canned Fish and Byproducts, Fish and Wildlife Service, CFS 304, 1945: 15 (statist. for 1945).

Doubtful Reference:

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Negative References:

Alosa tyrannus De Kay (not of Latrobe), New York Fauna, Pt. 4, Fishes, 1842: 252, pl. 13, fig. 38 (descr., probably *Pomolobus aestivalis*).

Brevoortia tyrannus Henshall (not of Latrobe), Bull. U. S. Fish Comm., *14*, 1895: 211 (Tampa, Florida; presumably *B. patronus*); Evermann and Kendall, Proc. U. S. nat. Mus., *31*, 1906: 74 (synon., lit. on *Brevoortia*; cf. specimens from various localities, includ. two from Argentina; presumably *B. patronus*); von Ihering, Rev. Industr. Anim., 1 (3), 1930: 229 (N. and S. Amer. representatives compared from lit., econ. import.); Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 29 (habitat, Texas; this is *B. patronus*).

Brevoortia brevicaudata Goode 1879

Figure 90

Study Material. Eight specimens, 165–180 mm TL, 126–147 mm SL, all from Noank, Connecticut, USNM 14044, 14846. This species, as herein understood, is known only from the above specimens.

Distinctive Characters. See *Relationship* (p. 364).

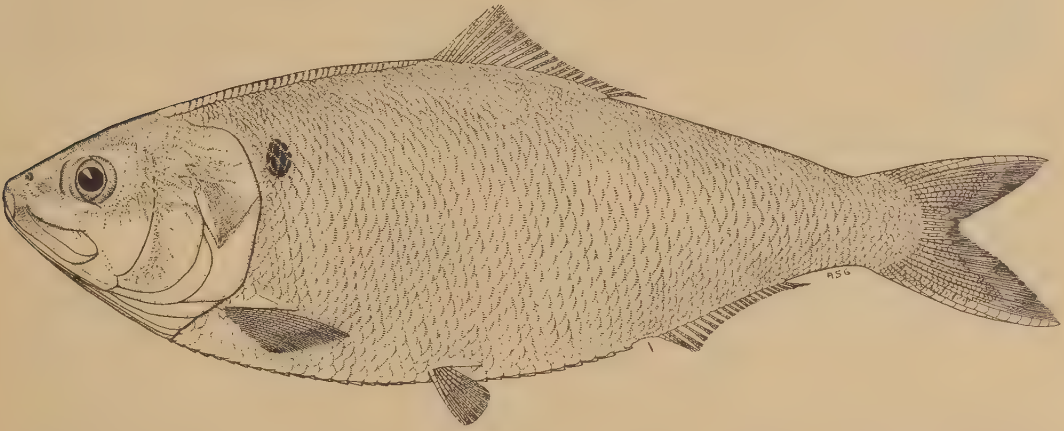

FIGURE 90. *Brevoortia brevicaudata,* 180 mm TL, 145 mm SL, Noank, Connecticut, type, USNM 129797. Drawn by Ann S. Green.

Description. Proportional dimensions in per cent of standard length, and counts, based on specimens 126–147 mm SL.

Body: depth 35–38.
Caudal peduncle: depth, 9.6–10.5.
Head: length 29–30.
Snout: length 6.4–7.3.
Eye: diameter 5.4–6.
Interorbital: width 6.2–7.0.
Maxillary: length 12–13.
Mandible: length 15.5–16.5.
Anal fin: length of base 17.5–19.
Pelvic fin: length 8.2–8.6.
Pectoral fin: length 13.5–16.
Scales: oblique series along middle of side 47–53.
Modified scales: in a series in front of dorsal fin, 35–39.
Ventral scutes: 31–33.
Fin rays: dorsal 19–22; anal 21 or 22; pectoral 17.
Vertebrae: 48 (1 specimen).

BODY deep and robust, its greatest thickness about a third of its depth, its greatest depth near midpoint between tip of pectoral and insertion of pelvic, 2.6–2.85 in SL. CAUDAL PEDUNCLE rather deep, 2.8–3.0 in head or 3.4–3.7 in greatest depth of body.

SCALES adherent, much deeper than long, with rather short pectinations as in *B.*

tyrannus of similar size, greatly reduced on back and at base of caudal; 5 or 6 vertical rows of scales exposed between tip of pectoral and base of pelvic fin. A row of large modified scales on each side of median line in advance of dorsal. VENTRAL SCUTES moderate, 18–20 in advance of pelvic fins and 12–14 behind them.

HEAD small, 3.3–3.85 in SL, its depth 3.6–3.8. SNOUT with a definite median notch, its length 3.9–4.6 in head. EYE small, 4.7–5.4. INTERORBITAL 4.1–4.7. CHEEK notably deeper than long. MAXILLARY rather short, reaching about to vertical from posterior margin of pupil, 2.2–2.4 in head. MANDIBLE short and included, its upper margin (within mouth) nearly straight, its length to joint 1.8–1.9 in head. Upper section of OPERCLE with prominent radiating ridges. GILL RAKERS long, and numerous, the longest ones about as long as snout and half of eye, about 115–125 on lower limb.

DORSAL fin low, its longest rays scarcely longer than the snout, its origin nearer to margin of snout than to base of caudal by a distance nearly equal to diameter of eye; its base with a low sheath composed for the most part of a single series of scales, not extending above the basal third of the rays. CAUDAL fin very short, the middle rays about as long as eye; lower lobe somewhat longer than upper one, more or less damaged, but shorter than head, about 3.7–4.4 in SL. ANAL very low, its origin under, or a little behind, vertical from tip of last dorsal ray, its base 5.25–5.7 in SL; a very narrow sheath of scales at base. PELVIC fin small, with a gently convex margin, its outermost ray not much longer than innermost ray; the fin inserted about under origin of dorsal; the length 3.4–3.6 in head. PECTORAL fin very short, not falcate, its length 7.25–8.25 in SL, or 1.8–2.2 in head, its longest ray about three times longer than the shortest one, failing to reach base of pelvic by a distance notably greater than diameter of eye. AXILLARY appendage of pectoral short and broad, only a little more than half of length of fin, 3.0–3.8 in head.

Color. Old preserved specimens dark greenish on back and upper part of side. Lower parts silvery to brassy. Sides of head silvery. A roundish dark spot at shoulder, about the size of pupil of eye; only one specimen at hand with suggestions of auxiliary dark spots on side behind shoulder spot. Fins all uniform brownish.

Relationship. It is strange that no additional specimens like the ones herein described, collected in 1874, are among the many in the U. S. National Museum from the general vicinity of Long Island and northward to Woods Hole, Massachusetts. These specimens differ in so many respects from the more or less typical *B. tyrannus* in the same general vicinity (Noank, Conn.) that it seems necessary to recognize them as representing a distinct species. The apparent distinctions are shown in a comparison with specimens of *B. tyrannus* of equal size from the same general vicinity of Noank (p. 365). It is evident from this comparison that *brevicaudata* is not a geographical variant.

The eight specimens in the *Study Material* are, in part at least, those studied by Goode, who gave measurements of two specimens from USNM 14846 and an accurate description (*44*: 33, 37); although he gave them the "variety" name *brevicaudata*, he did not designate a type. Therefore Goode's variety has been elevated to specific

Comparison of *B. brevicaudata* with *B. tyrannus*
(in per cent of standard length)

	brevicaudata	*tyrannus*		*brevicaudata*	*tyrannus*
HEAD: length	29–30.5	30.5–33	MANDIBLE: length	15.5–16.5	17.5–18.5
EYE: diameter	5.5– 6.0	6.2– 6.9	CAUDAL FIN: lower lobe	22.5–27	30–33
MAXILLARY: length	12–13	14–15	PECTORAL FIN: length	13.5–16	19.5–20

rank, with the designation of a lectotype approximately 180 mm TL (caudal somewhat damaged) and 145 mm SL, USNM 129797 (*58*: 10).

Thus the characters in all respects are smaller in *brevicaudata* than in *tyrannus*. The maxillary in the former reaches about to a vertical from the posterior margin of the pupil instead of well behind it; the caudal's lower lobe in *brevicaudata*, if measured from the middle of the caudal base, is shorter than the head instead of about equal to it in length; the pectoral in *brevicaudata* fails to reach the base of the pelvic by a distance exceeding the eye's diameter instead of less than its diameter, and it leaves 5–7 vertical series of scales exposed instead of 3 or 4, as in *tyrannus*.

If the specimens of *brevicaudata* are compared with examples from the southern part of the range of *tyrannus*, as from Fernandina, Florida, the differences are even more pronounced, for the head and eye in such material are relatively larger than those in northern specimens of *tyrannus*, and the fins are still longer.

Nothing distinctive is known about the life history of this species.

Range. Known only from Noank, Connecticut.

Synonyms and References:

Brevoortia tyrannus var. *brevicaudata* Goode, Proc. U. S. nat. Mus., *1*, 1879: 34, 37 (orig. descr.; type local. Noank, Connecticut; cotypes USNM 14846; cf. "normal" *tyrannus* and *aurea*).

Brevoortia tyrannus brevicaudata Goode, Rep. U. S. Comm. Fish. (1877), Append. A, 1879: 22 (said to vary from "normal type" with shorter maxillary and mandible, lower anal, and shorter caudal; Noank, Conn.); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 634 (cf. *aurea*, after Goode); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 44 (range, synon.).

Brevoortia brevicaudata Hildebrand, Smithson. misc. Coll., *107* (18), 1948: 10, fig. 2 (synon., descr., range, lectotype USNM 129797).

Brevoortia patronus Goode 1879

Largescale Menhaden, Gulf Menhaden, Alewife, Shad

Figures 84, 85, 91

Study Material. At least 110 specimens, 60–265 mm TL, 45–207 mm SL, collected at many places along the Gulf coast from Apalachicola, Florida, to Brazos Santiago, Texas, including the types of *B. patronus* Goode, USNM 892. Some of the data used were extracted from unpublished tables prepared by the late William W. Welsh; also a few lots of juveniles.

Distinctive Characters. See *Relationship* (p. 370).

Description. Proportional dimensions in per cent of standard length, and counts, based on at least 110 specimens, 45–207 mm SL.

Body: depth 33–45, usually 35–42.
Caudal peduncle: depth, 8.5–12.
Head: length 31–38, usually 32–35.
Snout: length 6.0–9.0, most frequently 7.0–8.0.
Eye: diameter 7.0–9.2.
Interorbital: width 6.5–8.0.
Maxillary: length 14–17, usually 15–16.
Mandible: length 17–20, most frequently 18 or 19.
Anal fin: length of base 17–21.
Pelvic fin: length 8.5–10.5.

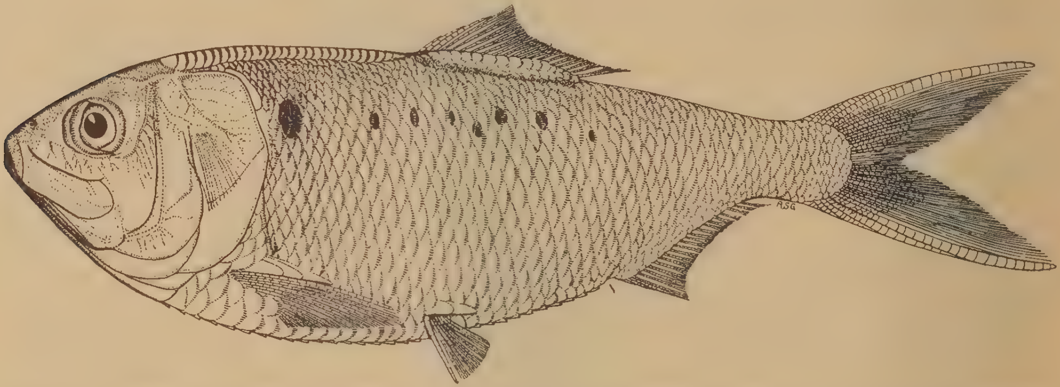

FIGURE 91. *Brevoortia patronus*, 215 mm TL, 164 mm SL, off Galveston, Texas, USNM 129810. Drawn by Ann S. Green.

Pectoral fin: length 19–23, most frequently 20–21.

Scales: oblique series along middle of side 36–50, usually 38–46.
Modified scales: in a series in front of dorsal 24–33, generally 25–31.
Ventral scutes: 28–32, most frequently 29–31.
Fin rays: dorsal 17–21, most frequently 19 or 20; anal 20–23; pectoral 14–17, most frequently 15 or 16.
Vertebrae: usually 45–47, rarely 42, 43, 44, or 48 (117 specimens).

BODY rather deep, strongly compressed, its greatest thickness about a third of its depth, the greatest depth well in advance of tip of pectoral and often only about an eye's diameter behind margin of opercle, 2.2–3.0, usually 2.4–2.8, in SL; ventral outline very strongly convex anteriorly, notably more than half of greatest depth of body below a line extending through lower margin of eye to middle of base of caudal. CAUDAL PEDUNCLE rather slender, 3.0–3.9, usually 3.2–3.7, in head.

SCALES adherent; the exposed part much deeper than long, the scale itself somewhat deeper than long (Fig. 85 A), the margin definitely serrate in young of about 60 mm, the serrae gradually increasing in length with age, becoming definitely pectinate, the pectinations reaching the full length of the otherwise exposed portion of the succeeding scale in specimens 200 mm TL and upward; scales greatly reduced in size on back and at base of caudal; rarely more than two rows of scales exposed between tip of pectoral and base of pelvic. A row of large modified scales on each side of median line of back in advance of dorsal fin, these scales not fully modified in examples less than about 100 mm TL, rather variable in number, generally about 25–31 in each series, therefore usually fewer than in *tyrannus*. VENTRAL SCUTES quite strong, more prominent in young than in adults, 18 or 19, rarely 16 or 17, in advance of pelvic fins, and 12 or 13, occasionally 11, behind them.

HEAD rather large, 2.6–3.2, usually 2.9–3.1, in SL, its depth 2.7–3.4, most frequently 2.8–3.2. SNOUT blunt, with a prominent median notch, its length 3.9–5.0, most frequently 4.2–4.6, in head. EYE with comparatively little adipose tissue, 4.1–5.0, usually 4.3–4.8. INTERORBITAL 4.1–5.0, usually 4.3–4.7. CHEEK much deeper than long in adults. MAXILLARY generally reaching vertical from posterior margin of pupil, 2.0–2.4, usually 2.1–2.2, in head. MANDIBLE included in upper jaw, its upper margin (within mouth) straight, its length to joint 1.75–1.9 in head. Upper section of OPERCLE with strong radiating ridges. GILL RAKERS very numerous, those on upper limb extending down and over those on lower limb, the longest ones rather longer than snout; increasing in number with age, about 40–50 in specimens 25–40 mm TL, 80–85 in specimens 45–60 mm, 125–130 in specimens 100–130 mm, and 135–150 in examples 200 mm and upward. TEETH wanting, except for minute ones on margin of maxillary in small specimens under about 60 mm.

DORSAL fin rather high anteriorly, its margin definitely concave, its longest rays nearly as long as snout and eye, the last two rays considerably longer than the preceding ones, its origin about equidistant between margin of snout and base of caudal; a broad scaly sheath on the base of fin, almost covering the fin except for the last produced rays if the fin is deflexed, extending well above basal third of the shortest rays when standing erect. CAUDAL moderately forked, the middle rays exceeding length of eye by nearly diameter of pupil, the lobes rather long, the lower one often longer than head, 2.5–3.2, most frequently 2.8–3.1, in SL. ANAL moderately low, somewhat elevated anteriorly, its margin definitely concave, its origin under, or a little in advance of, tip of last dorsal ray, its base 4.75–5.9 in SL; a low scaly sheath at base. PELVIC fin small, with a gently convex margin, its length 3.1–3.7 in head, its outermost ray only a little longer than the innermost ray (Fig. 84 A); the fin inserted well behind vertical from dorsal origin. PECTORAL long, somewhat falcate in adults, its length 4.35–5.25, usually 4.75–5.0, in SL, 1.5–1.9, most frequently 1.5–1.7, in head, its longest rays about four times longer than the shortest one, sometimes nearly reaching base of pelvic. AXILLARY SCALE of pectoral variable, generally scarcely more than half of length of fin in large examples, little developed in young.

Color. Back bluish-gray. Sides brassy-green. Sides of head silvery. A large black shoulder spot, often followed by a single series (rarely by a double series) of smaller and less definite spots, these being roundish in some and vertically elongate in others; the shoulder spot generally appearing in specimens between a length of 50 and 75 mm, the auxiliary spots usually appearing later. Fins mostly plain yellowish green; the caudal with a dusky margin. Peritoneum jet black.

Size. A small size seems to be normal. An example 265 mm (10.6 in.) TL is the largest now at hand. Goode (*44*) quoted Silas Stearns as having seen examples 11, 12, and 13 inches long, but these may have been *gunteri.*

Development and Growth. The postlarvae, 19–24 mm TL and 16–19 mm SL, are relatively slender, though deeper than young of *tyrannus* of the same length, their greatest depth being about 7.4–10.5 in TL and 4.75–8.0 in SL. Also, these young fish are more advanced in development, for even the smallest ones have all fins (exclusive of the pectoral) well enough developed to show rays; however, the pelvic fin is still well in advance of the dorsal. The convoluted intestine, characteristic of young clupeoids generally, remains evident in the smaller examples but has become fully invaginated in the larger ones. The snout seems to be rather more pointed in the postlarvae than in larger fish, and the large rounded maxillary scarcely reaches beyond the anterior margin of the pupil. The gill rakers of the upper limb do not yet extend down and over those of the lower limb, and the filaments on the posterior rim of the gill arches are little developed at this size. The ventral scutes in front of the pelvics are well developed in the largest specimens, but not those behind them. The smallest specimens have a series of dark chromatophores along the lateral edge of the abdomen and another along the anal base; also, few dark chromatophores are present on the opercle, on the base of caudal, and on the chest; some of these markings have become obscure in the larger specimens of this lot. Dark specks, present on the caudal and dorsal fins, are decidedly more numerous in the larger specimens than in the smaller ones.

Specimens of about 30 mm already are shaped much like adults. Scales in part are developed, and general pigmentation has taken place, the lower part of the sides already being silvery in some specimens. The dark specks on the dorsal and caudal fins have increased greatly in number, but the chromatophores along the base of anal of juveniles remain faintly visible. The gill rakers have increased considerably in proportionate length, and those of the upper limb now extend downward across those of the lower limb; the filaments, too, are much better developed. The maxillary remains shorter than in adults, for it scarcely reaches below the middle of the eye. Striations are faintly visible on the upper part of the opercle, the ventral scutes are fully developed, and the pelvic fin now is situated under the anterior rays of the dorsal, as in adults. The dark peritoneum is plainly visible through the abdominal walls at this stage of development.

Little is known about the rate of growth. Length frequencies, based on 186 fish, suggest that a maximum length of about 100 mm (4 in.) is attained at one year of age, probably 150 mm (6 in.) at two years. However, some of the fish in each year-class are much smaller, some being only about 80 mm long at one year of age and about 125 mm at two years. The rate of growth seems to be about the same as that of *tyrannus* at Beaufort, North Carolina.

Reproduction. As in the case of their growth, little is known about reproduction in the Largescale Menhaden. Goode (*45*: 577) quoted Silas Stearns as follows:

> The first traces of spawn are found in May. But by July it has become sufficiently developed to be noticed by any person unaccustomed to the examination of such objects. In the latter part of September or first of October, at which time they are seen in abundance, the ovaries are sufficiently grown to distend the fish's abdomen, yet not fully ripe. When they are next caught, in November and December, on the sea-beach, they are without ovaries and show signs of having spawned.

Since the Gulf species, *patronus* and *gunteri*, were not distinguished until recently, one cannot be sure which species Silas Stearns observed. Even now it is not known whether the spawning seasons of the two are different.

The large examples at hand were all taken in February and March, and in these the gonads are in a collapsed state, as though the fish had spawned recently. Furthermore, the juveniles at hand, 28–60 mm TL, were taken in late winter and during the spring. In fact, there are some postlarvae, 19–24 mm TL, taken at Dead Man's Island, Corpus Christi, Texas, March 31, 1926, which are believed to be this species. Thus it is indicated that spawning takes place during the winter, that is, rather later in the year than the time suggested by Silas Stearns.

Migrations and Habitat. These Menhaden, like *tyrannus*, travel in schools while they feed on plankton at the surface. However, at times they apparently live at or near the bottom also, for the Bureau of Fisheries schooner, GRAMPUS, took many specimens with an otter trawl in February and March 1917 off Corpus Christi and Galveston, Texas. Gunter also reported their capture in the Gulf with an otter trawl (*51*: 29).

According to Gunter (*51*), this species was not taken in water having salinities below 25.0, which agrees in general with the places of collection of the specimens now at hand. At least all of the larger specimens of *patronus* were taken either offshore or in localities where the salinity would be expected to run rather high. However, small to half-grown examples are at hand that were caught where the water must have been nearly fresh, as at Manchac Pass on the Illinois Central Railroad, north of New Orleans, Louisiana, and in Grand Plains Bayou, near Baldwin Lodge, Mississippi. Such a habitat, for both young and adults, would correspond to that of *tyrannus*.

It was stated by Silas Stearns that the fish are not seen in shallow water during winter but appear in the spring and remain until late fall (*in* Goode, *45*). He said that in fine weather the fish could be seen approaching the coast in great schools, and that, once they had reached the inside waters, a large school would break up into smaller schools. He also said that quiet bayous, creeks, and nooks in the bay were favorite "feeding or playing grounds." Furthermore, he noted that small schools feed at the mouths of rivers, and that upon becoming "accustomed to the fresh water," they move upstream to quiet places. Again, one does not know whether Stearns observed one or both species inhabiting the Gulf.

Food. There is every reason to believe that the food of *patronus* is essentially the same as that of *tyrannus*. Both species feed at the surface in dense schools, have a gizzard-like stomach, and a long intestine, which suggest a vegetable diet. The presence of mud in the stomach suggests that they also feed on the bottom. Stearns said, "The Gulf menhaden are a bottom-feeding fish, as their stomachs always contain soft brown mud, from which I suppose they extract microscopic animal and plant matter" (*45*).

Parasites. As in Atlantic menhaden, the isopod *Olencira praegustator* (Latrobe) is frequently found in the mouth of Largescale Menhaden (*107*: 231). Stearns (*45*) likewise reported it, saying:

> When the Gulf Menhaden arrive in spring, each one has a parasite in its mouth, a crustacean called *Cymothoa praegustator*. This is found always in one position, clinging with its claws to the roof of the fish's mouth, with its head looking forward and very near to the jaws of the fish. The parasites remain with the menhaden as long as the latter is in salt water; in brackish water they are less frequently observed, disappearing altogether in fresh water. With all the fall fish of this species which I have examined there were no parasites.

Once more it is possible that Stearn's observations may have been based on one or both species inhabiting the Gulf.

Two species of copepods, *Bomolochus teres* Wilson and *Lernanthropus brevoortiae* Rathbun, have been reported as parasitic on Gulf *Brevoortia* (*12*: 582, 588), but it is not known whether one or both species served as host.

Relationship. This species, closely related to *tyrannus* of the Atlantic coast, generally has been considered identical to it or only subspecifically distinct. However, it differs in so many respects from *tyrannus* that it apparently must be recognized as a distinct species. Furthermore, the range of the two species is discontinuous, for neither occurs in southern Florida, south of the Indian River on the Atlantic or south of Tampa on the Gulf.

The body depth in *patronus* compared with *tyrannus* is a bit greater, the shape is different, the head and body are deeper anteriorly, and the ventral outline is notably more strongly convex. The deepest part of *patronus*' body is well in advance of the tips of the pectoral fin and only about an eye's diameter behind the margin of the opercle, whereas in *tyrannus* it usually is over the tip of the pectoral and notably more than an eye's diameter behind the margin of the opercle. The differences in shape are plainly evident in Figs. 86 and 91. Also, in *patronus* the fins generally are longer, the scaly sheath on the base of the dorsal is broader, the axillary process of the pectoral usually is shorter, and the modified scales in front of the dorsal are larger and have shorter pectinations; in fact, overlapping in the number of modified scales is slight, occurring in only some of the rather numerous specimens examined.

The extremes of variation, as well as the usual variation, are given in the *Description*, and from those data it is evident that some overlapping occurs in every proportion and count. Nevertheless, the average differences are great in some of them. The more outstanding ones are the following, with those for *patronus* given first (in per cent of standard length): depth 38.8, 34.2; head (length) 33.6, 32.2; head (depth) 33.5, 27.8; pectoral fin 20.9, 18.7; lower lobe of caudal 34.3, 29.4; vertebrae 45.8, 48.0; scales along middle of side 41.7, 48.2; modified scales on back in advance of dorsal fin 28.0, 36.0; and ventral scutes 29.8, 32.5.

The differences in shape and depth of body, already mentioned, are more outstanding in young adults than in mature individuals. In fact, the depth in *patronus* is already about as great in fish 40–60 mm TL as in large ones; in examples of *tyrannus* of similar size the body is notably more slender; for example, in 34 specimens of *patronus* falling within the range mentioned, the depth is 36.4–45.0 % of SL, whereas in 60 examples of *tyrannus* the range is 25.8–35.8.

Variation. It is not evident at present that specimens vary between different areas, as in those from Florida at one extreme of the range and those from Texas at the other. Sufficient specimens for a thorough study of variation are at hand from Texas only. The young, as stated elsewhere, acquire the shape of the adult very early in life, and the pronounced variation in depth of body is therefore an individual variation rather than one of age. There is also considerable variation in the number and intensity of the dark spots on the side, with some specimens, including large ones, having only a shoulder spot (p. 367).

Commercial Importance. Commercial utilization of *patronus* is a recent development. Statistics at hand show for 1940 a catch of menhaden for Mississippi only, this being 25,194,000 pounds. For 1950–1953, however, the following catches (probably *patronus* for the most part but including some *gunteri*) were reported for the Gulf coast (in pounds): 326,030,100 for 1950, 351,965,100 for 1951, 459,983,900 for 1952, and 437,045,000 pounds, valued at $ 5,189,000, for 1953.

Range. Gulf coast of Florida to Texas. It was recorded once for as far south on the western Florida coast as Tampa (55: 211), but at present there are no specimens in the National Museum collection from farther south than Apalachicola, Florida. There are many from as far west and south as Corpus Christi, and the types (USNM 892) are from Brazos Santiago, Texas.

Synonyms and References:

Brevoortia patronus Goode, Proc. U. S. nat. Mus., *1*, 1879: 39 (orig. descr.; "descr." based on specimens from Brazos Santiago, Texas [USNM 892]; "diagnosis" based in part on specimens from "Mouth of Rio Grande" [USNM 891], which are *B. gunteri*; "table of measurements" includes both species); Goode, Rep. U. S. Comm. Fish. (1877), 1879: 26 (after Goode, 1879); Jordan and Gilbert, Bull. U. S. nat. Mus., 16, 1882: 269 (descr., may be based in part on *B. gunteri*); Goode *in* Goode *et al.*, Fish. Fish. Industr. U. S., 1 (3), 1884: 575, pl. 206 (movements, parasites, reprod., food); Richardson, Bull. U. S. nat. Mus., 54, 1905: 21 (isopod parasite); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 44 (range, synon.); Gunter, Ecol. Monogr., *8*, 1938: 355 (season. var. in abund., Louisiana); Hildebrand, Smithson. misc. Coll., *107* (18), 1948: 13, fig. 3 (synon., relation., descr., range).

Brevoortia tyrannus patronus Evermann and Kendall, Bull. U. S. Fish Comm. (1892), *12*, 1894: 105, pl. 21 (Galveston, Texas; differences between Atlantic and Gulf specimens slight); Evermann, Rep. U. S. Comm. Fish. (1898), 1899: 309 (many young at Grand Plains Bayou, Mississippi); Weymouth, Proc. U. S. nat. Mus., *38*, 1911: 136 (Cameron, Louisiana); Fowler, Monogr. Acad. nat. Sci. Philad., *7*, 1945: 365, 372 (refs., occur.).

Brevoortia tyrannus Henshall (not of Latrobe), Bull. U. S. Fish Comm. (1894), *14*, 1895: 211 (Tampa, Florida); Evermann and Kendall, Proc. U. S. nat. Mus., *31*, 1906: 74 (synon., discus. lit. on *Brevoortia*; cf. specimens from various locals.; descr. of two from Argentina); Bere, Amer. Midl. Nat., 17 (3), 1936: 582, 598 (copepods); Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 29 (Texas coast habitat).

Brevoortia smithi Hildebrand 1941

Yellowfin Shad

Figures 84, 85, 92

Study Material. A total of 18 specimens, 120–315 mm TL, 91–240 mm SL, collected at Beaufort, North Carolina; Cumberland Sound, Georgia; and at the "mouth of St. Johns River" and in the "Indian River," Florida; the type, 295 mm TL, 225 mm SL, included among the material from Beaufort, USNM 118723. Also, specimens from Boca Ciega, Pinella County, and off Englewood, coast of western Florida, that are intermediate in some respects between *B. smithi* and *B. gunteri*, received through the kindness of William Gosline.

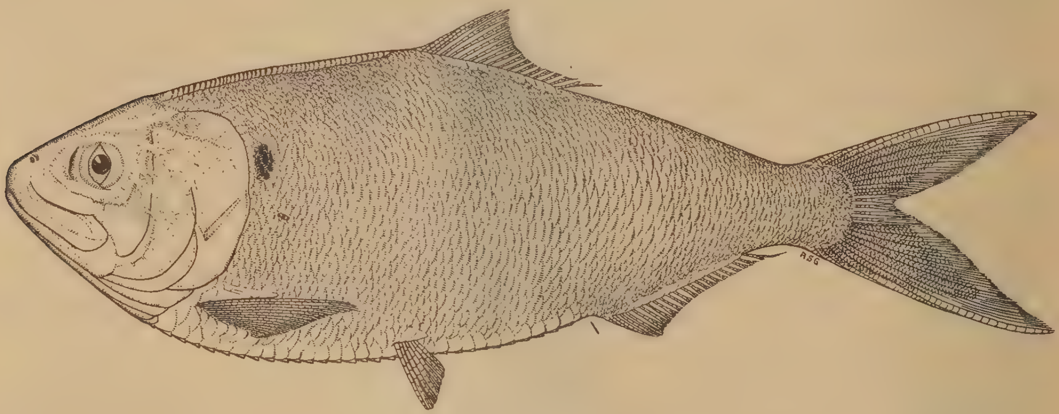

FIGURE 92. *Brevoortia smithi*, 295 mm TL, 225 mm SL, Beaufort, North Carolina, type, USNM 118723. Drawn by Ann S. Green.

Distinctive Characters. See *Relationship.*

Description. Proportional dimensions in per cent of standard length, and counts, based on specimens listed in the *Study Material*, 91–240 mm SL.

Body: depth 36–43.
Caudal peduncle: depth 9.5–12.
Head: length 29–32.5.
Snout: length 6.8–8.0.
Eye: diameter 6.1–7.5.
Interorbital: width 6.2–7.4.
Maxillary: length 13.5–15.
Mandible: length 17–18.5.
Anal fin: length of base 19–21.
Pelvic fin: length 8.5–11.
Pectoral fin: length 18.5–21.5.
Scales: oblique series along middle of side (too irregular to count accurately) *ca.* 60–70.
Modified scales: in a series in front of dorsal fin, 39–45.
Ventral scutes: 30–32.
Fin rays: dorsal 18–20; anal 22 or 23; pectoral 16 or 17.
Vertebrae: 45–47 (9 specimens).

BODY deep, rather strongly compressed, its greatest thickness notably less than half of the depth, its greatest depth at vertical from a point somewhat in advance of origin of dorsal and about midway between tip of pectoral and base of pelvic, 2.3–2.75 in SL; ventral outline notably more strongly convex than the dorsal outline, more than half of the greatest depth being below a straight line drawn through lower margin of eye to middle of base of caudal. CAUDAL PEDUNCLE rather deep, 2.6–3.4 in head, and 3.5–4.0 in greatest depth of body.

SCALES closely adherent, the exposed part three or more times deeper than long, the scales themselves less than two times deeper than long (Fig. 85 D); scales with prominent serrae ending in blunt points, not long or hair-like and not extending across exposed part of next scale; the scales greatly reduced in size on back and at base of caudal, in rather irregular series (difficult to count accurately); about 5–8 rows of scales exposed between tip of pectoral and base of pelvic. A row of enlarged modified scales on each side of median line of back in front of dorsal fin, the scales variable in number, 39–45 in each series. VENTRAL SCUTES not strong, 18 or 19 in front of pelvics, 12–14, most frequently 13, behind them.

HEAD 3.2–3.4 in SL, its depth 3.25–3.6. SNOUT compressed, blunt, with a prominent median notch, its length 3.7–5.0 in head. EYE 4.2–5.2. INTERORBITAL 4.2–4.9. CHEEK much deeper than long. MAXILLARY broadly rounded, reaching from under middle of eye to posterior margin of pupil, 2.1–2.3 in head. MANDIBLE included in upper jaw, its upper margin (within mouth) nearly straight, its length to joint 1.7–1.9 in head. Upper section of OPERCLE with very feeble radiating striae. GILL RAKERS very numerous, those on upper limb extending downward and over those on lower limb, the longest ones fully as long as snout, 121–149 in adults. TEETH absent.

DORSAL fin rather high anteriorly, the margin rather deeply concave, the longest rays equal to length of snout and eye to posterior margin of pupil, the last ray considerably longer than preceding ones, the origin about equidistant between margin of snout and base of caudal; a very low sheath on base of fin, composed of a single row of scales. CAUDAL deeply forked, the middle rays about as long as eye, the lobes long, the lower one slightly the longer, exceeding the length of head, 2.7–3.1 in SL. ANAL notably lower than dorsal, little elevated anteriorly, its margin nearly straight, its origin under or a little behind tip of last ray of dorsal, its base 4.75–5.25 in SL; a very narrow sheath at base. PELVIC fin with an oblique margin, its length 2.8–3.4 in head, its outermost ray nearly twice the length of the innermost one, the fin inserted under or slightly behind vertical from origin of dorsal. PECTORAL fin long, scarcely falcate, its length 4.65–5.4 in SL and 1.45–1.75 in head, its longest ray fully four times longer than the shortest one, the fin failing to reach base of pelvic by a distance somewhat greater than half of diameter of eye. AXILLARY APPENDAGE of pectoral variable, reaching to or well beyond midlength of fin, 2.6–4.0 in head.

Color. Back, in fresh specimens, bluish green, lighter than in *tyrannus* (evident also in preserved specimens). Sides silvery. A large black spot at shoulder, not followed by smaller dark spots. Fins golden yellow; the margin of caudal paler than rest of fin. Peritoneum black.

Size. The largest example seen, taken at Beaufort, North Carolina, was 330 mm (13.2 in.) TL. This is about equal to the usual length of fish that compose the fall and winter runs of *tyrannus* in the same vicinity.

Reproduction and Development. Nothing is known about reproduction in this species, notwithstanding the fact that the eggs and young were sought diligently at Beaufort, North Carolina, for about six years. The several adults taken there during spring and summer and examined in the laboratory showed no signs of development.

The smallest specimen at hand, 120 mm TL, differs from large ones in having a deeper body and less strongly serrated scales. The last mentioned difference is quite in keeping with other species of *Brevoortia*, for the serrations (pectinations) apparently increase in length with age in all species. It has been pointed out that young adults of *patronus* are quite as deep as large ones, which is contrary to the rule in *tyrannus*. The very deep-bodied young adults of *smithi* suggest that the young of this species too may acquire a deep body at an early age.

Migrations and Habits. Yellowfin Shad were taken at Beaufort, where their occurrence was observed several years in succession. They seem to be present there only during spring and summer and only in the local estuaries. If they occur off Beaufort Inlet, where large *tyrannus* are taken, they escaped our nets. Although the fish probably leave brackish water to spawn, the adults, contrary to those of *tyrannus*, do frequent brackish water during a portion of the year.

According to fishermen at Beaufort, these Menhaden do not school. This was confirmed by our investigations, for we took at most 10–12 a day in a pound net operated for several years in the estuary of Newport River, and rarely were more than two taken in a single haul with a large collecting seine. In contrast, hundreds of *tyrannus*, if taken at all, generally were present when the pound net was fished.

Yellowfin Shad are much more active fish than *tyrannus*. When they are caught in a seine they dash here and there and strike the net again and again in an effort to escape, whereas *tyrannus* generally strike the net once and then allow themselves to be hauled in without making a further effort to flee. The two species, when once their habits are known, may be identified by their behavior when surrounded by a seine.

Food. These fish, like *tyrannus* and other species of menhaden, have a thick-walled gizzard-like stomach and a long intestine. A fish 330 mm TL and 247 mm SL, for example, had an alimentary canal 937 mm long; that is 380 % of its SL. The stomach contents of this same specimen consisted of diatoms and spicules of a sponge.

Parasites. Only one parasitic copepod (*Lernaeenicus radians*)[40] has been found on these Menhaden. The conspicuous isopod *Olencira praegustator*, very common in the mouth of *tyrannus*, has not been seen thus far in *smithi*.

Relationship. The differences between *Brevoortia smithi* and *B. gunteri* are given on p. 379. *B. smithi* differs from *B. tyrannus* in having much smaller scales, in less regular series; notably shorter serrations or pectinations on the scales of specimens of equal size (Figs. 85 B and 85 D); more feeble radiating striations on the upper part of the opercle; and a longer and more pointed pelvic fin. Furthermore, *B. smithi* has a rather more strongly compressed and deeper body and a deeper caudal peduncle, a somewhat smaller head, a rather larger anal fin with a somewhat greater number of rays and a longer base, and somewhat longer caudal and pectoral fins. Also, *B. smithi* is lighter in color, has more definitely yellow fins, and has no small dark spots behind the large shoulder spot. The two species are separable by touch, as *tyrannus* is very slimy and slippery whereas *smithi* is not.

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[40] Identification by Paul L. Illg, at the U. S. National Museum.

Variations. The variations among the limited number of specimens known are not pronounced. The smallest specimen, 120 mm TL, from Cumberland Sound, Georgia, is the deepest among the 18 at hand, which suggests that in this species, as in *patronus*, young adults are as deep or deeper than large ones, whereas in *tyrannus* they are more slender. However, some half-grown fish from the mouth of the St. Johns River, Florida, are no deeper than large fish from Beaufort. The great difference in the number of gill rakers (121–149) on the lower limb may be ascribed in part to age and in part to an error in counting, as it is impossible to count the close-set rakers accurately. The fresh examples observed in the field were quite uniform in color.

Commercial Importance. Yellowfin Shad are not numerous enough to be commercially important, for only a few are taken at a time. The total annual catch at Beaufort probably does not exceed several hundred pounds. Their abundance south of Beaufort remains unknown.

The fishermen, at least at Beaufort, distinguish these Menhaden from the common one and refer to them as the "Yellowfin Shad." They claim that the edible qualities are superior to those of *tyrannus*, and the few they catch are generally put on their own table. I like the flavor of both species and could detect no difference except that the flesh of *smithi* may be a little less oily.

Methods of Fishing. The fish are caught chiefly in drag nets at Beaufort, the only place where they seem to be recognized as a distinct species.

Range. Known from Beaufort, North Carolina, to the "Indian River" (probably Indian River City), Florida, while specimens intermediate between *gunteri* and *smithi*, from Boca Ciega and from off Englewood on the west coast,[41] are nearer to *smithi* than to *gunteri*.

Synonyms and References:

Brevoortia aureus Hildebrand (not of Agassiz), Rep. U. S. Comm. Fish. (1918), Append. 6, 1919: 7, fig., pl. 1, fig. 2, scale (orig. descr. of *B. smithi* Hildebrand 1941; habits, food, cf. *B. tyrannus*; Beaufort, North Carolina).

Brevoortia smithi Hildebrand, Copeia, 1941: 224 (*B. aureus* Hildebrand recognized as a distinct species without a name; type local. Beaufort, N. C.; type USNM 118723); Hildebrand, Smithson. misc. Coll., *107* (18), 1948: 28, fig. 6 (synon., descr., relation., range).

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[41] Made available for examination through the kindness of Dr. William Gosline.

Brevoortia gunteri Hildebrand 1948

Finescale Menhaden

Figures 84, 85, 93

Study Material. A total of 55 specimens, 70–310 mm TL, 53–230 mm SL, from bays in the vicinity of Corpus Christi, Rockport, and Galveston, Texas, including several small ones from the mouth of the Rio Grande and from Brazos Santiago, part of Goode's type material of *patronus*, which included two species (*44*: 39); and from Grand Isle, Louisiana (one specimen); all in the USNM collections.

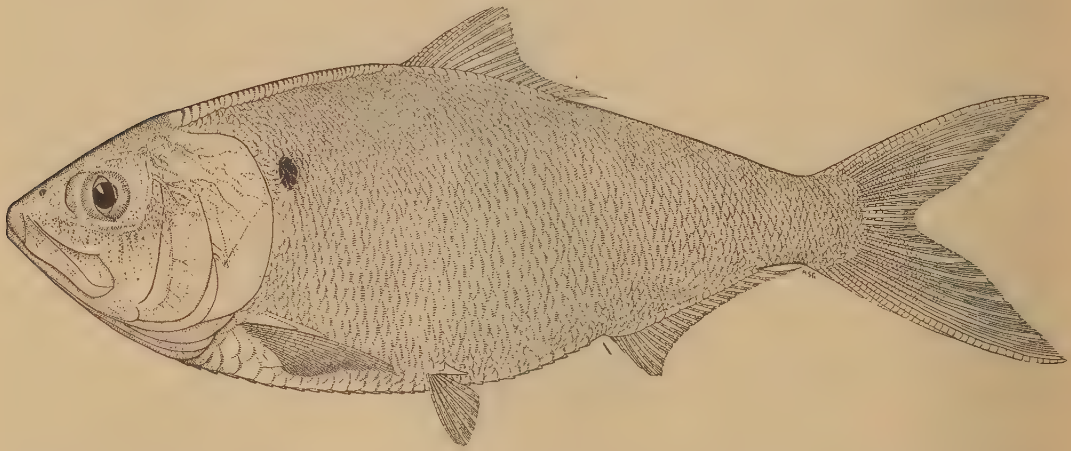

FIGURE 93. *Brevoortia gunteri*, 270 mm TL, 205 mm SL, Rockport, Texas, type, USNM 129798. Drawn by Ann S. Green.

Distinctive Characters. See *Relationship*.

Description. Proportional dimensions in per cent of standard length, and counts, based on the study specimens, 53–230 mm SL.

Body: depth 37–45, most frequently 38–41.

Caudal peduncle: depth, 9.5–12.5, most frequently 10–11.

Head: length 31–35.5, most frequently 32–34.

Snout: length 7.0–10.

Eye: diameter 6.6–9.5.

Interorbital: width 7.0–8.0.

Maxillary: length 14.5–17.5, most frequently 15.5–16.5.

Mandible: length 17.5–20.5, most frequently 18.5–19.

Anal fin: length of base 19–23, most frequently 20.5–22.5.

Pelvic fin: length 9.3–11.

Pectoral fin: length 19–23.5, most frequently 20–22.

Scales: oblique series along middle of side (too irregular to count accurately) about 60–75.

Modified scales: in a series in front of dorsal 35–45, most frequently 38–42.
Ventral scutes: 27–30, usually 28 or 29.
Fin rays: dorsal 17–20, most frequently 18 or 19; anal 20–25, most frequently 22–24; pectoral 15 or 16, rarely 14.
Vertebrae: 43 or 44, rarely 42 (22 specimens).

Body deep, strongly compressed, its greatest thickness only about a third of its depth, its greatest depth, at a vertical slightly in advance of origin of dorsal or the tip of pectoral, 2.2–2.7 in SL; ventral outline notably more convex than the dorsal one, much more than half of greatest depth below a straight line extending through lower margin of eye to middle of base of caudal. Caudal peduncle rather deep, 2.7–3.5 in head, and 3.6–4.0 in greatest depth of body.

Scales closely adherent, the exposed part 3–4 times deeper than long, the depth of scale itself about twice its length (Fig. 85 c); adults with prominent serrae ending in somewhat blunted points, not long or hair-like and not extending quite across the exposed part of the next scale; the scales much reduced in size on back and on base of caudal, in rather irregular series (difficult to count accurately); about 2–4 vertical rows of scales exposed between tip of pectoral and base of pelvic. A row of enlarged modified scales on each side of median line of back in front of dorsal fin, rather variable in number, 35–45 in each series. Ventral scutes weaker in large examples than in small ones, 17 or 18, usually 17, in front of pelvic fins, and 10–13, usually 11 or 12, behind them.

Head 2.7–3.2 in SL, its depth 2.75–3.4. Snout compressed, with a sharp median notch, its length 3.4–4.4 in head. Eye 3.6–4.8, most frequently 4.2–4.7. Interorbital 4.1–4.7. Cheek deeper than long. Maxillary broadly rounded, reaching to, or a little beyond, vertical from posterior margin of pupil, 1.9–2.2, usually 2.0–2.1, in head. Mandible included in upper jaw, its upper margin (within mouth) nearly straight, its length to joint 1.55–1.95 in head. Upper section of Opercle with very feeble radiating striae, or none. Gill rakers very numerous, those on upper limb extending downward and across those on upper part of lower limb, the longest ones somewhat exceeding length of snout; increasing in number with age and growth: 97 on lower limb of first arch in a specimen 70 mm TL, 113–120 in specimens 100–115 mm, and 135–150 in specimens 200–300 mm. Teeth absent in all specimens at hand.

Dorsal fin rather high anteriorly, its margin rather deeply concave, its longest rays about as long as snout and half of eye, the last ray considerably longer than the ones immediately before it, its origin generally about equidistant between the margin of snout and base of caudal; a very narrow sheath on its base, composed of a single row of scales. Caudal deeply forked, the middle rays about as long as eye, the lobes long, the lower one the longer, exceeding length of head, 2.55–3.1, usually 2.8–2.9, in SL. Anal fin much lower than dorsal, its margin somewhat concave, its longest rays about 0.33 as long as those of dorsal, its origin under, or a little in advance of, tip of last dorsal ray, its base 4.45–5.25 in SL; a narrow sheath of scales at base. PELVIC fin with a nearly straight oblique margin, its length 2.9–3.4 in head, its outermost ray somewhat less than twice the length of the innermost ray (Fig. 84 c), the fin inserted a little behind vertical from origin of dorsal. PECTORAL fin long, slightly falcate, its length 4.25–5.25 in SL, and 1.4–1.9 in head, its longest ray fully four times longer than the shortest one, the fin failing to reach the base of pelvic by a distance usually a little less than diameter of pupil. AXILLARY APPENDAGE of pectoral variable in length, apparently increasing in length with age, usually about half of length of fin in large examples and only about a third in small ones, 2.5–4.6 in head.

Color. Preserved specimens dark gray above a line extending through upper margin of eye to slightly above middle of base of caudal, changing rather abruptly to the silvery color of the side. A large black shoulder spot in adults, only faintly visible on those 110–125 mm long, absent in smaller ones, this spot not followed by smaller dark spots in any specimen at hand. Dorsal and caudal fins somewhat dusky, the margin of the caudal pale; other fins plain translucent. Gunter, when comparing fresh examples of this Menhaden with *patronus*, remarked: "The second species [*gunteri*] . . . was more silvery and had less green color" (*51*: 27). Peritoneum black.

Size. The specimens examined run larger in size than those of *patronus*; quite a few exceed a length of 230 mm (9.2 in.), and the largest has a length of 310 mm (12.4 in.). An example 313 mm (12.5 in.) long has been reported (*51*).

Development and Growth. The eggs of this species remain unknown, and very little has been learned about the development, for no specimens less than 50 mm SL are included in the collections examined. However, there is no reason to believe that *gunteri* and *patronus* differ essentially in their development. Judging from the smaller specimens at hand, the indications are that the young of this species, at an early age, reach a depth of body that is equally as great as that in large adults, as in the case of *patronus*. The increase in the number of gill rakers with age and growth is shown in the *Description*.

In somewhat more than four months, in 1942, from the time of their capture on February 25 until July, 0-class postlarvae 21–30 mm long (identified by Gunter as this species) grew to lengths of 25–45 mm (*51*). Gunter also spoke of a group 88–113 mm long that predominated in Aransas and Copano bays in November and December. Although he did not definitely assign these fish to the 0-class, he did conclude that "The curves indicate that this menhaden attained a length of 88 to 113 mm at the age of one year." This is about the same size as that indicated for *patronus* at a year of age.

Spawning. Gunter has reported that a 12.5-mm male taken in Aransas Bay on February 25, 1942, was exuding milt and that a ripe female 15.0 cm long was taken in Copano Bay on March 29, 1942 (*51*: 28). From Gunter's observations it appears that this species, like *patronus*, spawns during the winter, and possibly into early spring.

Migrations and Habitat. Nearly all that is known about the migrations and habitats of *B. gunteri* has been given by Gunter (*51*), the only student who seems to have recognized this species as distinct from *patronus*. He found *gunteri* to be much more common in Aransas and Copano bays than *patronus*, and he expressed the opinion that it probably is "completely euryhaline," though he did add that his data strongly suggest a midwinter exodus from Copano Bay but not from Aransas Bay. The fact that all specimens of *gunteri* in the U. S. National Museum collection were collected in inshore waters and that most of the *patronus* samples were taken offshore support Gunter's contention. However, there are some small to half-grown specimens of *patronus* in the collections that were taken inshore, where the water must have been decidedly brackish.

The habitats of *gunteri* and *patronus* in the Gulf therefore seem to parallel those of their close relatives in the Atlantic. However, *gunteri* has been reported as schooling by Gunter, and if correct, then *gunteri* apparently differs in that respect from *smithi*, which does not school while inhabiting the estuaries of Beaufort, North Carolina (p. 374).

Food. B. gunteri also is a plankton feeder, and "it may be seen in schools twisting and turning through the water, with mouth agape . . ." (*51*).

Relationship. This species differs from *patronus*, its relative in the Gulf, in having much smaller and more crowded scales, which are placed in less regular series and which in adults have notably shorter serrations (pectinations). It differs further in having much more feebly developed radiating striae, or none, on the upper part of the opercle and in the absence of dark spots behind the black shoulder spot. Gunter also said that it is not slimy when fresh, like *patronus*.

Its nearest relative is *smithi* of the Atlantic. Both of these species have deep, well-compressed bodies that are almost void of slime, small crowded scales, no dark spots on the anterior part of the body behind the black shoulder spot, and several other similar characters. But they differ in that the head is rather longer and deeper in *gunteri*, the body is more strongly compressed, the maxillary and mandible are somewhat longer, as is the pectoral fin, the ventral scutes are nearly always fewer, the scales are proportionately deeper, and the vertebrae, so far as known, are definitely fewer. But the presence on the coast of western Florida of Finescale Menhaden somewhat intermediate between *gunteri* and *smithi* emphasizes the desirability of a more detailed comparison of them than has been made as yet.

Variation. The specimens at hand vary considerably in depth, as shown in the *Description*; the smaller specimens in general are deeper than the larger ones. The variation in the number of anal rays is also rather great. The wide range shown for the number of oblique series of scales along the middle of the side may be ascribed in large part to the difficulty of counting them accurately. The great difference noted in the number of gill rakers on the lower limb of the first arch results largely from their increase in number with age. The color is quite uniform among the larger examples, but the smaller ones are lighter in color, and those less than about 115 mm TL lack the black shoulder spot.

Commercial Importance. No Menhaden plants are operated at present on the coast of Texas where this species seems to be common, and it is not known whether it is included among the menhaden processed in Mississippi. Neither is it known to what extent *gunteri* may have contributed to the reported Texas catches of 47,190,800 pounds of "menhaden" for 1950, 30,121,200 pounds for 1951, 52,983,600 pounds for 1952, and 589,300,000 pounds for 1953. Because of the extreme thinness of the fish, it probably would not yield much oil.

Range. Grand Isle, Louisiana, to the mouth of the Rio Grande, Texas.

Synonyms and References:

Brevoortia patronus Goode (in part *B. gunteri* Hildebrand), Proc. U. S. nat. Mus., *1*, 1879: 39 (diagn., tables based in part on *B. gunteri*).

Brevoortia sp. Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 27 (second species from Gulf, but not named; relation with other *Brevoortia* spp.; habitat, food, habits, spawn.).

Brevoortia gunteri Hildebrand, Smithson. misc. Coll., *107* (18), 1948: 31, fig. 7 (orig. descr.; type local. Aransas Bay, Texas; type USNM 129798).

Genus *Opisthonema* 1861

Opisthonema Gill, Proc. Acad. nat. Sci. Philad., 1861: 37; genotype by original designation, *O. thrissa* Gill equals *O. oglinum* (LeSueur).[42]

Characters. Body elongate, well compressed, its greatest depth exceeding length of head. Bony scutes with sharp points, about 32–36 on sharp edge of chest and abdomen. Cheek notably longer than deep. Vertical part of Clavicular margin (underneath opercle) with two small projections or lobes. Mouth of moderate size. Maxillary failing to reach middle of eye. Upper jaw without definite median notch. Lower jaw projecting beyond the upper. Teeth missing. Dorsal with about 17–21 rays, the last ray greatly produced, often reaching nearly to base of caudal. Anal with about 20–25 rays, the last one not greatly enlarged. Pelvic fin with 8 rays, inserted under base of dorsal fin, generally well behind origin of dorsal. Pectoral without an axillary process, lying in a slight depression. Vertebrae about 46–48.

Remarks. The chief distinguishing characters are the large dorsal fin, with nearly or equally as many rays as the anal and with the last ray greatly produced, frequently so that it reaches nearly or quite to the base of caudal; the projecting lower jaw with its abruptly ascending upper margin within the mouth; the long shallow cheek; the small pelvic, with 8 rays, inserted behind the origin of the dorsal; and the absence of a process (scale) in the axil of the pectoral.

Range. The genus is known on the Atlantic coast of America from Cape Cod, Massachusetts, to southern Brazil, and from the West Indies. On the Pacific coast it is known to range from the Gulf of California to Peru.

[42] It is probable but not certain that Gill intended this generic name for the fish now known as *O. oglinum*. *Clupea thrissa* Linnaeus (*84*: 318) has been applied to both a Chinese and an American species, which many older authors considered identical; at the time Gill wrote (1861), they were generally so considered. In fact it was not until 1917 that they were properly separated. Regan (*106*: 308) cleared up the confusion, and Herre and Myers (*56*: 234) have diagnosed still more carefully the Chinese *Clupanodon thrissa*.—G. S. M.

Opisthonema oglinum (LeSueur) 1817

Atlantic Thread Herring, Hairyback, Shad Herring, Bristle Herring, Sargo, Sargo de Gato, Sardinha Large, Sardinha Sargo

Figure 94

Study Material. A total of 65 or more specimens, 65–250 mm TL, 50–182 mm SL, from Massachusetts, Rhode Island, New Jersey, Virginia, North Carolina, Georgia, Florida (both coasts), and Texas; Atlantic coast of Panama; Colombia; at Recife, Barro Santos, and São Francisco, Brazil; Cuba; Puerto Rico; Jamaica; Haiti; Barbados; and Trinidad. Also several lots of juveniles from Beaufort, North Carolina; Key West, Florida; Mustang Island, Texas; Colón and Portobello, Panama.

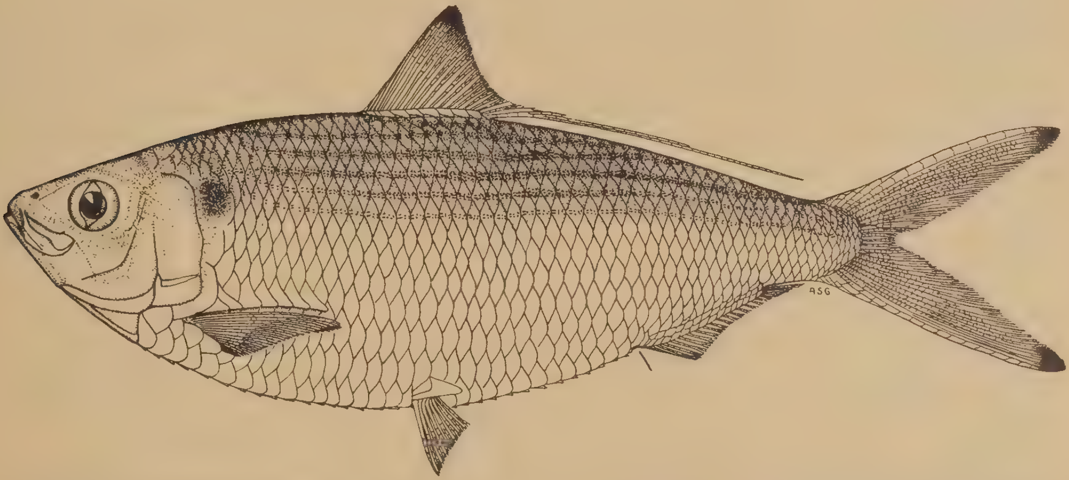

FIGURE 94. *Opisthonema oglinum*, 220 mm TL, 167 mm SL, Beaufort, North Carolina, USNM 51873. Drawn by Ann S. Green.

Distinctive Characters. See *Relationship.*

Description. Proportional dimensions in per cent of standard length, based on study specimens, 150–182 mm SL.

Body: depth 30–40.
Caudal peduncle: depth 8.5–11.
Head: length 22–28.
Snout: length 5.3–7.3.
Eye: diameter 6.0–8.5.
Interorbital: width 5.0–6.7.
Maxillary: length 8.8–12.
Anal fin: length of base 16.7–21.5.
Pelvic fin: length 8.5–11.5.
Pectoral fin: length 17–21.

Scales: 43–50.
Ventral scutes: 32–36.
Fin rays: dorsal 17–21, most frequently 19 or 20; anal 21–25, most frequently 22–24; pectoral 15–17.
Vertebrae: 45–48 (15 specimens).

BODY elongate, rather strongly compressed, its greatest thickness often only a third of the depth, its depth variable, generally greatest at origin of dorsal, 2.5–3.33 in SL; ventral outline strongly convex, the dorsal outline typically only gently convex, making the body when viewed from the side rather definitely boat-shaped. CAUDAL PEDUNCLE depth 2.3–2.8 in head.

SCALES only moderately adherent, thin, notably deeper than long, with somewhat irregular membranous edges; 3 or 4 vertical rows of scales exposed between tip of pectoral and base of pelvic. VENTRAL SCUTES moderately developed, 18 or 19, occasionally 17, in front of pelvic fins, and 14–16, occasionally 13 or 17, behind them.

HEAD small, 3.5–4.5. SNOUT blunt, without a definite median notch, 3.4–4.5. EYE moderately large, slightly longer than snout, 3.0–4.0. INTERORBITAL 3.8–5.7. CHEEK much longer than deep. MAXILLARY broadly rounded, reaching about to vertical from anterior margin of pupil, 2.15–2.75. MANDIBLE slightly projecting, its tip definitely lower than dorsal outline of head, its upper margin (within mouth) ascending abruptly, forming an obtuse angle. GILL RAKERS very numerous, close-set, those on upper limb not extending down and over those on the lower limb, the longest about 0.33 of diameter of eye; increasing in number with age and growth: about 40–50 on lower limb in specimens 40–60 mm TL and up to 100 or more in adults about 235 mm TL. TEETH not discernible.

DORSAL fin elevated anteriorly, the longest among the anterior rays generally exceeding length of snout and eye, the last ray filamentous, rather variable in length, most frequently reaching vertical from base of last ray of anal; origin of fin about half as far from posterior margin of eye as from base of caudal, the distance from margin of snout approximately 33 % of TL, or 2.3 in SL; a low sheath of scales on base of fin. CAUDAL deeply forked, its middle rays about as long as eye, its lobes long, the lower one 3.0–3.5 in SL. ANAL fin scarcely elevated anteriorly, its margin nearly straight, its last ray slightly enlarged, its origin only about a third as far behind vertical from last dorsal ray as from base of caudal, its base 1.1–1.6 in head; a low sheath of scales at base. PELVIC fin small, pointed when folded, with a nearly straight oblique margin when spread, its length 2.1–2.8 in head, its innermost ray about 66 % of length of the outermost one, the fin inserted a little in advance of vertical from middle of base of dorsal, its distance from origin of anal equal to distance from origin of anal to base of caudal. PECTORAL fin moderately long, its margin nearly straight, pointed, lying in a slight depression, its length from base of upper ray to tip of fin, 4.75–5.8 in SL, or 1.1–1.6 in head, its shortest rays only about half as long as the longest ones. AXILLARY PROCESS absent.

Color. Back bluish-green in life, the rest of body silvery. A dark shoulder spot usually present. Rows of scales on back with more or less definite dark lines. Fins chiefly translucent, the dorsal and caudal lobes generally with dark tips.

Size. A length of 300 mm (12 in.) has been reported. The size generally is much smaller, however, the usual length being only about 200–250 mm (8–10 in.).

Development and Growth. The eggs and larvae have not been described. The smallest specimens, about 22–25 mm long, rather certainly identified as this species, were taken at Key West, Florida, on August 25, 1919, but they are not in good condition, having been partly dried. Although they cannot be used for obtaining proportions, it is evident from these and others that the proportionate depth of the body in examples under 25 mm is much less than in those 100 mm and more. In fact, those up to 75 mm long generally are notably more slender than adults, though there is much individual variation at all sizes.

The chief distinctive marks in the smallest young at hand are the projecting lower jaw; the long shallow cheek; the shallow concavity in the margin of the opercle in front of the pectoral fin; the positions of the fins, which correspond to those of the adult; and the number of dorsal and anal rays, which already can be counted with a fair degree of accuracy. The last ray of the dorsal becomes prolonged much earlier in some individuals than in others; for example, it already is somewhat produced in a specimen 30 mm TL from Mustang Island, Texas, but in others up to 37 mm long from Beaufort there is no sign of prolongation. Ventral scutes can be accurately counted when the fish attain a length of about 30 mm, and even earlier in some examples. The gill rakers, as shown in the *Description*, increase in number with age and growth.

The color of the young is rather variable. The smallest ones have a silvery lateral band (dark in some lots of specimens, presumably due to preservative used) that increases in width with age and merges with the generally silvery color of the side in some specimens only 35–40 mm long; but it remains visible in others up to a length of 50 mm or so. In some young, as in some adults, the shoulder spot is absent whereas it is quite evident in others at a length of 35 mm. Occasionally there are smaller dark spots within the lateral band behind the shoulder spots; these may or may not disappear when the lateral band merges with the silvery color of the side. The black peritoneum is often visible through the body wall in the young.

Little is known about the rate of growth. A few measurements made at Beaufort indicate that the fish attain a length of about 35–60 mm at the age of one year and 90–120 mm by the end of their second summer. Sexual maturity, at least in some individuals, is reached at a length of only 150 mm.

Spawning. At Beaufort, North Carolina, spawning takes place during May and June, as determined from the gonads of adult fish.

Migrations and Habitat. These Thread Herring often school, but solitary examples were frequently taken at Beaufort, North Carolina, and on the Atlantic coast of Panama. They hold more closely to salt water than menhaden and some other Clupeidae and are not known to migrate inshore to spawn. They are essentially tropical and subtropical fish, and although they stray northward to Cape Cod, they generally are not numerous north of North Carolina. In North Carolina, where they usually are abundant during the summer, they are taken from May through September.

Food. These fish, like most of their relatives, feed largely on small organisms, which they strain from the water with the numerous close-set gill rakers. Copepods constituted the chief food of specimens from Chesapeake Bay (*59*: 101). However, small fish, crabs, and shrimp were also found in the stomachs of fish from Port-au-Prince, Haiti (*10*: 42).

The stomach does not have a thick wall, as in the menhaden (p. 355) and the gizzard shad (p. 443). Neither is the intestine especially long, being only about 1.33 °/₀ of TL of adult fish. Possibly to compensate for the relatively short alimentary canal, the stomach is provided with about 100 pyloric coeca.

Enemies. No doubt they are preyed upon by many predatory fishes, such as the bluefish, Spanish mackerel, weakfish, and many others. Pelicans also feed on them, especially when the fish school at the surface.

Relationship and Variation. This species is the only one of the genus recognized from the Atlantic. However, it has a near relative on the Pacific coast of tropical America, from which typical specimens of *oglinum*[43] differ in having a deeper body with a more strongly convex ventral outline, longer fins, and no small dark spots behind the shoulder spot.

In addition to these differences, there are the variations with age. The body becomes deeper as growth proceeds, especially up to a length of 100 mm or so, and the gill rakers apparently increase in number as long as the fish grow. Insufficient specimens have been studied critically to determine geographical variations. It would seem probable from the limited data based on specimens of about equal size that those from South America and the West Indies generally are rather deeper than those from the Atlantic coast of the United States and have on an average one more ventral scute.

Commercial Importance. The flesh has been reported as being dry, bony, and of inferior flavor. At Beaufort they are seldom used as food, and during a residence there for ten summers I saw none in the market. However, they appear rather regularly in the markets in Colón, Panama, and in the West Indies. At Beaufort and perhaps elsewhere on the shores of the southern states, they are sometimes taken with purse seines by the crews of menhaden boats and delivered to the menhaden reduction plants. However, the amount of oil yielded is very small. Such catches do not reach the statistical reports, presumably because they are not separated from menhaden.

Range. Middle Atlantic States, sometimes straying northward to Cape Cod; southward to southern Brazil (São Francisco); common throughout the West Indies.

Synonyms and References:

Megalops oglina LeSueur, J. Acad. nat. Sci. Philad., *1*, 1817: 359 (orig. descr.; type local. Newport, Rhode Island).

Megalops notata LeSueur, J. Acad. nat. Sci. Philad., *1*, 1817: 361 (orig. descr.; type local. Guadeloupe, West Indies; said to have longer dorsal than *oglina*, also a shorter produced dorsal ray and different color, etc.).

Chatoessus signifer DeKay, N. Y. Fauna, Pt. 4, Fishes, 1842: 264, pl. 41, fig. 132 (orig. descr.; type local. New York; type in State Coll.; cf. *C. thrissa* Bloch and *M. oglina* LeSueur).

Meletta thrissa Cuvier and Valenciennes (not *Clupea thrissa* Linnaeus 1758), Hist. Nat. Poiss., *20*, 1847: 380 (orig. descr.; type locals. New York, Santo Domingo, Guadeloupe, and Martinique).

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[43] It is entirely possible that a more critical study than time now permits would reveal the existence of more than one species on the Atlantic coast of the Americas. Specimens from Bermuda, and some from the Atlantic coast of Panama, were not used in preparing the *Description* because it was suspected that they may prove to be separate and distinct.

Alausa striata Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 429 (orig. descr.; type local. Guadeloupe).

Chatoessus eumorphus Gosse, Naturalist's Sojourn in Jamaica, 1851: 290 (orig. descr.; type local. Jamaica).

Opisthonema thrissa Poey (not *Clupea thrissa* Linnaeus 1758), Repert. Fisico-Nat. Cuba, 1868: 419 (refs., diagn., etc.); Enumerat. Pisc. Cubens., 1875: 148 (refs., distr.); Uhler and Lugger *in* Rep. Comm. Fish. Md., ed. 1, 1876: 158; ed. 2, 1876: 134 (descr., synon., Maryland); Metzelaar, Rapp. Vissch. Curaçao, ed. by Boeke, 1, West Indian Fishes, 1919: 12 (when caught, import. as foodfish, local name, range, Curaçao and St. Eustatius).

Clupea thrissa Günther (not of Linnaeus), Cat. Fish. Brit. Mus., *7*, 1868: 482 (synon., descr., range).

Opisthonema oglinum Henshall, Bull. U. S. Fish Comm. (1889), *9*, 1891: 373 (common, w. coast of Florida; Big Gasparilla and Egmont Key); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 101 (descr., size, range); Jordan and Rutter, Proc. Acad. nat. Sci. Philad., 1897: 94 (refs., Kingston, Jamaica); Evermann and Bean, Rep. U. S. Comm. Fish. (1896), 1898: 241 (in nest of pelican, counts, Indian R., Florida); Smith, Bull. U. S. Fish Comm. (1897), 17, 1898: 91 (Woods Hole, Massachusetts); Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 56 (Florida); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 86 (descr., range, synon., Puerto Rico); Schreiner and Miranda-Ribeiro, Arch. Mus. nac., Rio de J., *12*, 1903: 92 (Brazilian recs., notes); Bean, T. H., Bull. N. Y. St. Mus., 60, Zool. 9, 1903: 209 (synon., descr., range, local occur.); Barbour, Bull. Mus. comp. Zool. Harv., *46*, 1905: 112 (distr., Bermuda); Fowler, Rep. N. J. St. Mus. (1905), 1906: 102 (descr., refs., New Jersey); Rep. N. J. St. Mus. (1906), 1907: 266, fig.; Smith, N. C. geol. econ. Surv., *2*, 1907: 129 (refs., diagn., size, food value, range, Beaufort, North Carolina); Kendall, Occ. Pap. Boston Soc. nat. Hist., 1908: 40 (refs., New England); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31* (2), 1913: 742 (Woods Hole, Massachusetts); Starks, Stanf. Univ. Publ., Univ. Ser., 1913: 8 (var. in depth, Natal, Brazil); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 385 (synon., descr., range); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 187 (synon., descr., range, Atlantic, Panama); Nichols and Breder, Zoologica, N. Y., *9* (1), 1926: 41, fig. (New York and s. New England); Hildebrand and Schroeder, Bull. U. S. Bur. Fish. (1927), *43* (1), 1928: 101 (refs., descr., food, range, Chesapeake Bay); Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 42, fig. (refs., descr., size, range, food, Port-au-Prince, Haiti); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 41 (diagn., range); Truitt, Bean, and Fowler, Bull. Md. Conserv. Dep., 3, 1929: 51 (descr., Maryland); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 68, fig. (distr., food, size); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 203, fig. (distr., esp. West Indies and Puerto Rico, diagn.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 44 (range, synon.); von Ihering, Rev. Indust. Anim., 1 (3), 1930: 230 (counts, discus., Brazil); Howell-Rivero, Handbk. Jamaica, 1936: 1, in reprint (small specimens, color, size); Hollister, Zoologica, N. Y., *21* (23), 1936: 284, fig. 49 (caudal skel., Bermuda); Bigelow and Schroeder, Bull. U. S. Bur. Fish., *48*, 1936: 327 (Monomoy Pt., Cape Cod, Massachusetts); von Ihering, Dict. Anim. Brazil, 1940: 716 (note, common names); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 134 (refs., Brazil); Bertin, Bull. Soc. Zool. Fr., *66*, 1941: 24 (*Alausa striata* C. and V. design. a synon.); Oliveira, Serv. Agr. Dep. nac. Producao Animal, Caca e Pesca, Rio de J., 1942: 24 (descr.); Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 25 (Texas).

Genus *Harengula* Cuvier and Valenciennes 1847[44]

Sardines

By

Luis René Rivas

Harengula Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 277; type species, *H. latulus* Cuvier and Valenciennes (not *Clupea latulus* Cuvier 1829) equals *Clupea clupeola* Cuvier 1829.

Characters. Ventral scutes 25–32, usually 26–31. Scales 38–44, usually 39–43. Vertical anterior edge of shoulder girdle (Clavicular margin) with a bilobed dermal fold. Upper jaw without distinct median notch. Gill rakers on epibranchial of first arch not folding downwards over those on the ceratobranchial; 26–40, usually 27–39, on lower limb of first arch. Last ray of Dorsal fin not produced into a long filament. Fin rays: dorsal 17–20, usually 17 or 18; anal 15–19, 17–19 in western Atlantic species, usually 16–18; pelvic 7–9, usually 8; pectoral 13–17, usually 15 or 16. Vertebrae 40–44.

Size. The maximum size is about 170 mm.

Range. Western North Atlantic in coastal waters of Bermuda, and from Florida southward to Brazil. Pacific coast from the Gulf of California southward to Peru.

Habits. Sardines are plankton feeders, and occur close to the coast, especially in estuaries, where they usually congregate in compact schools near the surface. Certain species ascend streams for short distances, but not beyond brackish water.

Abundance and Relation to Man. Sardines are most abundant in bays and estuaries where they may be captured with beach seines and cast nets. They are used for bait and food throughout the West Indies and are utilized in the canning industries of Cuba and Venezuela.

Key to Species

1a. Inner edge of palatines with a row of pointed teeth anteriorly; gill rakers 26–32, usually 27–31, on lower limb of first arch; ventral scutes 25–29, usually 27 or 28; scales not adherent, easily falling off from either fresh or preserved specimens; snout 2.5–3.4, usually 2.6–3.3, in distance between origins of pelvic and anal fins; humeral spot absent. Average length 80–140 mm.

humeralis Cuvier 1829, p. 387.

1b. Inner edge of palatines without a row of pointed teeth anteriorly; gill rakers

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[44] Contribution No. 44 from the Ichthyological Laboratory and Museum, Department of Zoology, University of Miami.

28–40, usually 30–39, on lower limb of first arch; ventral scutes 28–32, usually 29–31; scales adherent, not falling off from either fresh or preserved specimens; snout 3.4–4.3, usually 3.5–4.2, in distance between origins of pelvic and anal fins; humeral spot present, sometimes faint. Average length 40–90 mm.

2a. Scales in 42–44, usually 43, transverse rows, and 12 or 13, usually 12, longitudinal rows; predorsal scales 15–19, usually 16–18.
thrissina Jordan and Gilbert 1882.
Pacific coast of México from the Gulf of California to Acapulco.

2b. Scales in 38–42, usually 39–41, transverse rows, and 11 longitudinal rows; predorsal scales 11–14, usually 12 or 13.

3a. Anal with 15–17, usually 16, rays, its base usually slightly shorter than pelvic fin; tip of dorsal fin blackish. *peruana* Fowler and Bean 1923.
Pacific coast from Panama to Peru.

3b. Anal with 17–19, usually 18, rays, its base usually slightly longer than pelvic fin; tip of dorsal fin not blackish.

4a. Gill rakers 28–34, usually 30–32, on lower limb of first arch.
clupeola Cuvier 1829, p. 390.

4b. Gill rakers 30–40, usually 32–39, on lower limb of first arch.
pensacolae Goode and Bean 1879, p. 393.

Harengula humeralis (Cuvier) 1829

Red-ear Sardine, Sardina, Sardina de Ley, Sardine, Loosescale Sardine, Pilchard, Red-ear Pilchard, Sprat, Whitebill, Pincer

Figure 95

Study Material. Numerous specimens, 44–172 mm SL, from Florida, Bermuda, West Indies, and the Caribbean coast of Central America, USNM, MCZ, and UMIM.

Distinctive Characters. The presence of pointed anterior palatine teeth, the reduced number of gill rakers (26–32) and ventral scutes (25–29), and the nonadherent loose scales distinguish this species from all the others of this genus.

Description. Proportional dimensions in per cent of standard length, and counts, based on 577 specimens, 44–172 mm SL.

Body: greatest depth 26.0–30.7; greatest width 13.5–16.0.
Caudal peduncle: least depth 9.5–11.2.
Head: length 27.1–32.8; depth at occiput 22.4–25.9.
Snout: length 7.7–9.2.
Eye: diameter 8.7–11.3.
Interorbital: width 5.5–6.6.
Maxillary: length 12.4–15.3.
Dorsal fin: anterior height 18.5–23.2; length 22.2–26.0; length of base 16.6–19.0.

Anal fin: anterior height 5.6–9.9; length 18.8–21.3; length of base 14.8–16.9.

Pelvic fin: length 11.0–14.4.

Pectoral fin: length 18.2–22.1.

Distance from tip of snout to origin of: dorsal fin 43.8–46.3; anal fin 76.2–78.4; pelvic fin 51.6–55.5; pectoral fin 26.2–30.5.

Scales: transverse rows 38–42; predorsal 9–11.

Ventral scutes: 25–29, usually 27 or 28.

Gill rakers: 26–32, usually 27–31, on lower limb of first arch.

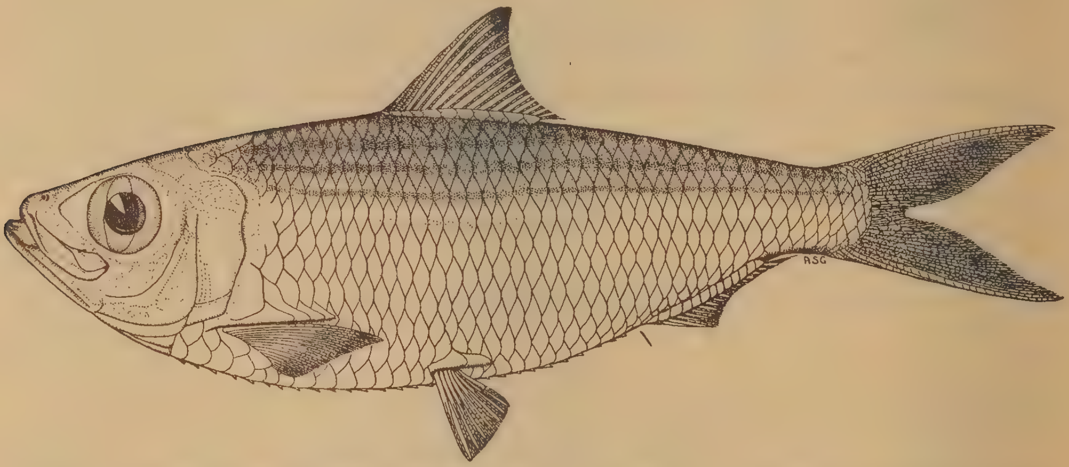

Figure 95. *Harengula humeralis*, gravid female, 210 mm TL, 158 mm SL, Tortugas, Florida, USNM 116873. Drawn by Ann S. Green.

Predorsal contour evenly and moderately convex, the Postdorsal contour more or less straight from origin of dorsal fin to caudal fin; Ventral contour much more convex than the dorsal, the body axis much closer to dorsal than to pelvic fins. Dorsal fin originating nearer to tip of snout than to caudal base. Pelvic fin inserted about midway between insertion of pectoral and origin of anal. Pectoral fin inserted about midway between tip of snout and insertion of pelvic, or (usually) nearer pelvic.

Color. General coloration silvery, especially on lower half of head and body; the opercular plates with iridescent or pearlish, metallic reflections. Back brownish gray. Sides of body with longitudinal streaks. Humeral spot absent. Tip of snout and mandible dusky. Upper sector of iris dusky. Tip of dorsal fin dusky; pectoral, pelvic, and anal fins colorless; tip of caudal lobes dusky, the pigmentation extending along their inner margins.

Size. This is the largest species of the genus. The largest examined measures 172 mm SL.

Range. Florida Keys, Bahamas, West Indies, and Caribbean coast of Central and South America, from Yucatán to Venezuela; also Bermuda.

Synonyms and References:

Clupea humeralis (not *Harengula humeralis* Cuvier and Valenciennes 1847) Cuvier, Règne Anim., ed. 2, *2*, 1829: 318, ftn. (name only, applied to Duhamel's fig. 4 of "Sardine des Antilles," 1776); Jordan, Proc. U. S. nat. Mus., *9*, 1887: 561 (synon. in part, West Indies).

Harengula maculosa Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 292 (orig. descr., life colors, Martinique); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 387 (synon., descr., range, Bermuda; Florida; West Indies); Jordan, Copeia, 1918: 46 (validity); Fowler, Proc. Acad. nat. Sci. Philad., *82*, 1930: 269 (Grenada); Proc. biol. Soc. Wash., *43*, 1930: 145 (size, Bermuda); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, App. 10, 1930: 43 (part. synon., West Indies); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 41 (nomencl.); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 8, 9 (char. in key, synon., remarks, life colors, char., range, Tortugas, Florida).

Alosa apicalis Müller and Troschel *in* Schomburgk's Hist. Barbados, Fishes, 1848: 675 (orig. descr., Barbados); Hill, Handbook of Jamaica, 1881: 125 (comments, Jamaica); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 41 (nomencl., orig. descr. quoted).

Harengula sardina Poey, Memorias, Cuba, *2* (49), 1860: 310 (orig. descr., Cuba); *2* (50), 1861: 384 (Cienfuegos, Cuba); Repert. Fisico.-Nat. Cuba, *2*, 1866: 16; 1868: 418 (spec. poison., char., compar., Cuba); An. Soc. esp. Hist. Nat., *5*, 1876: 147 (ref., compar.); Jordan and Bollman, Proc. U. S. nat. Mus., *11*, 1889: 550 (Green Turtle Cay, Bahamas); Jordan, Proc. U. S. nat. Mus., *12*, 1890: 645 (comments); Bean, Bull. U. S. Fish Comm., *8*, 1890: 206 (length, Cozumel, Yucatán); Jordan and Thompson, Bull. U. S. Bur. Fish., *24*, 1905: 233 (Tortugas, Florida); Fowler, Proc. Acad. nat. Sci. Philad., *58*, 1906: 83, fig. 2 (Hailer's Rock, Florida); Fowler, Proc. U. S. nat. Mus., *78*, 1926: 250 (scales, color, Boca Grande, Florida); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 202 (part. synon., type local., distr., diagn., Puerto Rico); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, App. 10, 1930: 43 (synon. in part, range); Longley, Carneg. Instn. Yearbk., 31, 1932: 299 (synon., Tortugas, Florida); Beebe and Tee-Van, Field Bk. Shore Fish. Bermuda, 1933: 35, fig. (field char., part. diagn., part. distr., Bermuda); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 41 (nomencl.); Howell-Rivero, Bull. Mus. comp. Zool. Harv., *82* (3), 1938: 171 (part. synon., type material, holotype design., Cuba); Butsch, J. Barbados Mus. Hist. Soc., 7 (1), 1939: 18 (Barbados).

Harengula jaguana Poey, Repert. Fisico-Nat. Cuba, *1*, 1865: 189 (comments, orig. descr., Bahia de Jagua, Cienfuegos, Cuba); *2*, 1868: 418 (char., compar., Cuba); An. Soc. esp. Hist. Nat., *5*, 1876: 147 (refs., type local., char., Bahia de Jagua, Cuba); Jordan, Proc. U. S. nat. Mus., *9*, 1886: 33 (compar.); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 41 (nomencl.).

Clupea macrophthalma (not of Ranzani, 1842), Günther, Cat. Fish. Brit. Mus., *7*, 1868: 421 (synon. in part, descr., range, West Indies).

Clupea apicalis Günther, Cat. Fish. Brit. Mus., 7, 1868: 441 (descr., Barbados); Jordan, Proc. U. S. nat. Mus., *9*, 1887: 561 (ref., West Indies); Cockerell, Inst. Jamaica Bull., 1, 1892: 15 (descr., Jamaica).

Harengula macrophthalma (not *Clupea macrophthalma* Ranzani 1842), Goode, Bull. U. S. nat. Mus., 5, 1876: 10, 13, 69 (use as bait, synon. exclud., range in part, abund., length, Bermuda and West Indies); Prov. Cat. Fish. Bermuda, 1877: 6 (Bermuda); Barbour, Bull. Mus. comp. Zool. Harv., *46* (7), 1905: 112 (distr. exclud., fin rays, scales, capture, abund., Bermuda).

Harengula callolepis Goode *in* Goode and Bean, Proc. U. S. nat. Mus., *2*, 1879: 152 (orig. descr., compar., Bermuda); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 4, 41 (nomencl.); Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 279, 285, 286, fig. 38 (char. in key, synon., comments, compar., Bermuda).

Clupea sardina Jordan, Proc. U. S. nat. Mus., *7*, 1884: 106 (abund., habitat, compar., descr., Key West); Jordan and Swain, Proc. U. S. nat. Mus., *7*, 1884: 230 (relation., scales); Jordan, Proc. U. S. nat. Mus., *9*, 1886: 33 (comments, Havana, Cuba); Rep. U. S. Comm. Fish., App. 2, E (24), 1887: 36, ftn. (descr., range, compar., synon. in part); Proc. U. S. nat. Mus., *9*, 1887: 561 (West Indies).

Clupea callolepis Jordan, Proc. U. S. nat. Mus., *9*, 1887: 561 (Bermuda).

Clupea sp. Lee, Rep. U. S. Comm. Fish. (1886), 1889: 672 (Nassau, Bahamas).

Harengula clupeola (not *Clupea clupeola* Cuvier 1829), Jordan, Proc. U. S. nat. Mus., *12*, 1890: 646, 647 (char. in key; Key West; and Havana, Cuba, synon. in part, St. Lucia, West Indies).

Sardinella apicalis Jordan and Evermann, Bull. U. S. nat. Mus., *47* (1), 1896: 428, 429 (char. in key, descr., part. synon., Barbados); Rep. U. S. Comm. Fish. (1895), 1896: 282 (range).

Sardinella sardina Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 428, 430 (char. in key, descr., range, synon.); Rep. U. S. Comm. Fish. (1895), 1896: 282 (range); B. A. Bean, Bahama Islands, Fishes, ed. Shattuck, 1905: 297 (range, abund., Nassau, Bahamas); Barbour and Cole, Bull. Mus. comp. Zool. Harv., *50* (5), 1906: 156 (Progreso, Yucatán); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 206 (Hailer's Rock, Florida); Rosen, Acta Univ. Lund., N. S. *7* (2), 1911: 48 (Nassau and Green Turtle Cay, Bahamas); Nichols, Bull. Amer. Mus. nat. Hist., *31* (18), 1912: 182 (market, Havana, Cuba); Bull. Amer. Mus. nat. Hist., *34* (7), 1915: 141 (San Juan Harbor, Puerto Rico); Bull. Amer. Mus. nat. Hist., *44* (3), 1921: 22 (Turks I., Bahamas); Metzelaar, Trop. Atlant. Vissch., 1, 1919: 11, fig. 3 (part. synon., size, habitat, Fuikbay, Curaçao, Aruba); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 183 (synon. in part, descr., range, Atlantic Panama); Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 40, fig. (ref., char., size, weight, color, range, distr., abund., capture, food, young, Port-au-Prince Bay, Haiti); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929, 1948: 68 (range, feed. habits, size, Florida); Parr, Bull. Bingham oceanogr. Coll., *3* (4), 1930: 2 (Bahama locals.).

Sardinella humeralis (not *Harengula humeralis* Cuvier and Valenciennes 1847), Evermann and Goldsborough, Bull. U. S. Fish Comm. (1901), 1902: 149 (descr., comments, Puerto Morelos, Yucatán); T. H. Bean, Field Mus. Publ., Zool., *7* (2), 1906: 34 (Bermuda).

Sardinella macrophthalma (not *Clupea macrophthalma* Ranzani 1842), Evermann and Marsh, Bull. U. S. Fish Comm., 1, 1902: 85 (descr., comments, range, synon. in part, Puerto Rico locals.); Breder, Bull. Bingham oceanogr. Coll., *1* (1), 1927: 12 (Royal I., Bahamas; Point Francis, Isle of Pines; Glover Reef, Brit. Honduras).

Sardinella macrophthalmus (not *Clupea macrophthalma* Ranzani 1842), T. H. Bean, Field Mus. Publ., Zool, *7* (2), 1906: 34 (Bermuda).

Sardinella maculosa von Ihering, Rev. Industr. Anim. São Paulo, 3, 1930: 228 (ref., diagn., comments, Brazil).

Harengula sp. Hollister, Zoologica, N. Y., *21* (4), 1936: 282–284 (caudal skel., Bermuda).

Harengula macropthalma (not *Clupea macrophthalma* Ranzani 1842) Fowler, Proc. Acad. nat. Sci. Philad., *89*, 1937: 309 (Haiti).

Harengula humeralis Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 13, 15, 21, 23, 24, 28, 39, 50 (char., relation., range, key, synon., descr., diagn.; St. Lucia; Glover Reef; Jamaica; Cuba; Florida Keys; Bahamas; nomencl., orig. descr. quoted); Fowler, Fish Culturist, *21* (9), 1942: 66 (use, size, compar., Cojimar, Cuba); Fish Culturist, 22 (2), 1942: 9 (size, length vent. fin, Bonacca I., Honduras); Monogr. Acad. nat. Sci. Philad., 6, 1944: 70, 93, fig. 27, 434, 456 (synon., ref., descr., compar., Serranilla Bank; w. Caribbean); Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 279, 282 (char. in key, synon., comment, compar., range).

Harengula clupeola (Cuvier) 1829

False Pilchard, Sardina Escamuda, Sprat, Petit Cailleu

Figure 96

Study Material. Numerous specimens, 43–149 mm SL, from Florida, the West Indies and the Caribbean coast of Central and South America, USNM, BOC, and UMIM.

Distinctive Characters. The absence of pointed anterior palatine teeth, the small number of gill rakers (28–35), higher ventral scute count (29–32), adherent scales, and slender body distinguish this species from all the other western Atlantic forms.

Description. Proportional dimensions in per cent of standard length, and counts, based on 252 specimens, 43–149 mm SL.

Body: greatest depth 29.5–32.0; greatest width 13.7–15.1.

Caudal peduncle: least depth 10.5–11.2.

Head: length 29.0–32.4; depth at occiput 25.9–27.8.

Snout: length 8.0–9.2.

Eye: diameter 9.1–11.5.

Interorbital: width 5.9–6.5.

Maxillary: length 13.6–15.2.

Dorsal fin: anterior height 18.8–20.8; length 21.2–25.2; length of base 16.3–17.1.

Anal fin: anterior height 5.9–8.2; length 17.5–21.1; length of base 14.2–19.7.

Pelvic fin: length 13.0–15.8.

Pectoral fin: length 21.5–22.9.

Distance from tip of snout to origin of: dorsal fin 44.3–47.5; anal fin 77.4–80.4; pelvic fin 52.8–56.2; pectoral fin 28.1–30.8.

Scales: transverse rows 40–43; predorsal 11–14.

Ventral scutes: 29–32, usually 30 or 31.

Gill rakers: 28–35, usually 30–32, on lower limb of first arch.

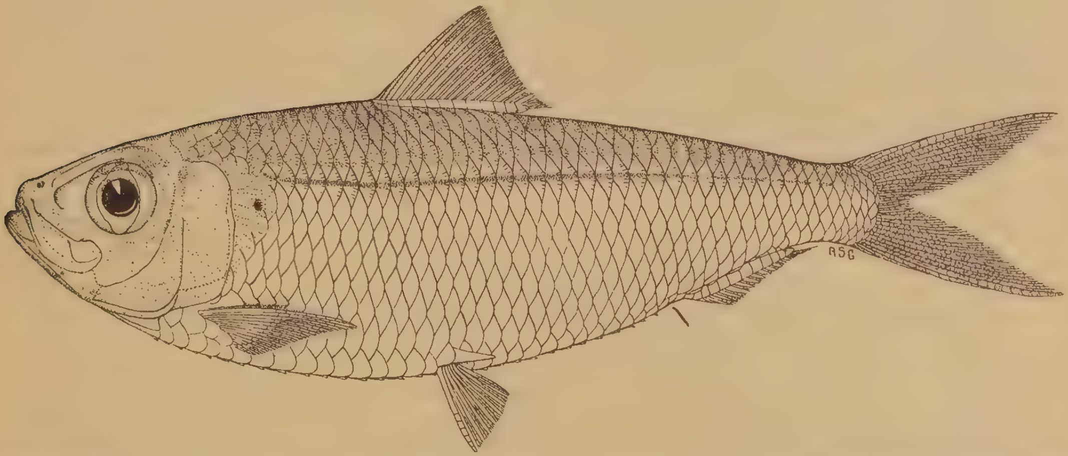

FIGURE 96. *Harengula clupeola*, gravid female, 180 mm TL, 138 mm SL, Tortugas, Florida, USNM 116872. Drawn by Ann S. Green.

PREDORSAL CONTOUR evenly and moderately convex, the POSTDORSAL CONTOUR more or less straight from origin of dorsal to caudal fin; VENTRAL CONTOUR much more convex than dorsal contour, the body axis closer to dorsal than to pelvic fins. DORSAL fin originating nearer to tip of snout than to caudal base. PELVIC fin inserted nearer to insertion of pectoral than to origin of anal. PECTORAL fin inserted closer to insertion of pelvic than tip of snout.

Color. General coloration silvery, especially on the lower half of the head and body; the opercular plates with iridescent or pearlish, metallic reflections. Back dark brownish or bluish gray. Body with dark, longitudinal streaks more conspicuous on back. Humeral spot faint. Tip of snout and mandible dusky. Upper sector of iris dusky. Fins colorless except caudal, which is somewhat pigmented at tip of lobes and along inner margin.

Size. This is the smallest species of the western North Atlantic, seldom reaching a length of more than 100 mm.

Range and Subspecies. H. clupeola is the most widely distributed species and has almost the same range as *Harengula humeralis*. It is known from the Florida Keys, Bahamas, West Indies, and Caribbean coast of Central and South America, from Yucatán to Brazil. The species does not show variation throughout its range whereby it can be broken up into geographical subspecies.

Synonyms and References:

Clupea clupeola Cuvier, Règne Anim., ed. 2, *2*, 1829: 318, ftn. (name only, applied to Duhamel's fig. 2 of "Petit cailleu," 1776); Règne Anim., Disciples ed., 1843: 274, ftn. (on "Petit cailleu" of Duhamel, 1776); Jordan, Proc. U. S. nat. Mus., *7*, 1884: 107 (compar., char.); Rep. U. S. Comm. Fish. (1885), App. 2, E (24), 1887: 33 (compar., Havana, Cuba); Proc. U. S. nat. Mus., *9*, 1887: 561 (part. synon., West Indies); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 42 (comments).

Clupea macrophthalma Ranzani, Novi Comm. Acad. Inst. Bonon., *5*, 1842: 320, pl. 23, figs. 1–4 (orig. descr., Brazil); Cope, Trans. Amer. philos. Soc., *14* (3), 1871: 483 (New Providence, Bahamas); Jordan, Proc. U.S. nat. Mus., *9*, 1887: 561 (synon. and ref. exclud., West Indies); Cockerell, Inst. Jamaica Bull., 1, 1892: 15 (teeth, color, Jamaica); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 44, fig. 15 (char., compar., holotype).

Harengula latulus (not *Clupea latulus* Cuvier 1829), Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 280, pl. 595 (orig. descr., Caen; Dieppe); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 3, 36, fig. 15 (comments, nomencl., type local. doubtful, on cotype, cf. *H. clupeola*).

Harengula clupeola Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 289 (descr., Martinique); Gosse, Naturalist's Sojourn in Jamaica, 1851: 210, 289 (used as bait, enemies, behav., Jamaica); Guichenot *in* Sagra, Hist. fisica. polit. nat. Cuba, *4* (2), 1853: 230 (diagn., comments, Cuba); Poey, Memorias, Cuba, *2* (49), 1860: 310 (cf. *H. sardina*); Memorias, Cuba, *2* (50), 1861: 384, 395 (compar., doubtful in Cuba); Repert. Fisico-Nat. Cuba, *1*, 1866: 378 (ref., range, Cuba); An. Soc. esp. Hist. Nat., *5*, 1876: 147 (ref., comment, range, Cuba); Hill, Handbook of Jamaica, 1881: 126 (Jamaica); Jordan and Bollman, Proc. U. S. nat. Mus., *11*, 1889: 550 (Green Turtle Cay, Bahamas); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, App. 10, 1930:43 (range, ref., West Indies); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 3, 13, 15, 23, 24, 29, 42, 49, 50, 51, figs. 1–3, 7–9, 11, 14, 16, 17 (relation., range, char., synon., descr., diagn., Panama; Glover Reef; St. Lucia; Puerto Rico; Jamaica; Cuba; Garden Key, Bahamas; nomencl. on *H. clupeola* C. and V. 1847 and on Poey's No. 377 sp. dubia, 1861); Fowler, Fish Culturist, *19* (4), 1939: 28 (Bimini, Bahamas); Arqu. Zool. estad. São Paulo, *3* (6), 1941: 133 (Brazil); Fish Culturist, *22* (2), 1942: 9 (vent. fin; Sheen Cay, Honduras); Monagr. Acad. nat. Sci. Philad., 6, 1944: 124, 434, 456, fig. 28 (synon., ref., descr., Old Providence I., Bahamas; w. Caribbean; Honduras); Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 280, 289–292, pl. 3, figs. 5, 6 (char. in key, synon., comments, compar., size, range).

? *Alosa bishopi* Müller and Troschel *in* Schomburgk's Hist. Barbados . . ., 1848: 675 (orig. descr.; compar., size, use as food, Barbados); Hill, Handbook of Jamaica, 1881: 125 (comments, Jamaica); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 49 (nomencl., orig. descr. quoted).

Harengula species dubia Poey, Memorias, Cuba, *2* (50), 1861: 384; Repert. Fisico-Nat. Cuba, *2*, 1868: 418 (descr., cf. *H. clupeola*, Cuba); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 49 (comments).

Clupea humeralis (not *Harengula humeralis* Cuvier and Valenciennes 1847), Günther, Cat. Fish. Brit. Mus., *7*, 1868: 422 (synon., ref., descr., range, all in part).

Harengula pensacolae (not of Goode and Bean 1879), T. H. Bean, U. S. Fish Comm., *8*, 1890: 206 (Cozumel, Yucatán).

Harengula macrophthalma Jordan, Proc. U. S. nat. Mus., *12*, 1890: 645, 646 (char. in key, synon. and ref. in part, Port Castries, St. Lucia); Jordan and Thompson, Bull. U. S. Bur. Fish., *24*, 1905: 233 (Garden Key, Tortugas, Florida); Fowler, Proc. Acad. nat. Sci. Philad., *67*, 1915: 257 (St. Vincent, Lesser Antilles); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 388 (synon. in part, descr., range, Florida; West Indies; Bahia; Fernando Noronha exclud.); Jordan, Copeia, 56, 1918: 46 (Atlantic spp.); Fowler, Proc. Acad. nat. Sci. Philad., *71* (2), 1919: 133 (St. Martin, Lesser Antilles); *80*, 1928: 462 (Puerto Rico); Nichols, New York Acad. Sci., *10* (2), 1929: 202 (synon. and ref. in part, distr., diagn., remarks, habits, fig., Puerto Rico); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, App. 10, 1930: 43

(range, synon. in part); Fowler, Proc. Acad. nat. Sci. Philad., *82*, 1930: 269 (Grenada); 89, 1937: 309 (Haiti); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 43 (nomencl., type local., orig. descr. quoted); Butsch, J. Barbados Mus. Hist. Soc., *7* (1), 1939: 18 (Barbados); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 8–10 (char. in key, compar., synon. in part, var. in depth accord. to sex, fin rays, vent. scutes, gill rakers, nomencl., range, Tortugas, Florida).

Clupea bishopi Cockerell, Inst. Jamaica Bull., 1, 1892: 15 (color, Jamaica).

Sardinella clupeola Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 428, 429 (char. in key, descr. in part, nomencl., ref.); Rep. U. S. Comm. Fish. (1895), 1896: 282 (range); B. A. Bean *in* Shattuck, Bahama Islands, Fishes, 1905: 297 (Green Turtle Cay, Bahamas); Metzelaar, Trop. Atlant. Vissch., 1919: 11, fig. 10 (synon., size, Haiti, drawing erroneously ident. as *Sardinella anchovia* C. and V. 1847).

Sardinella bishopi Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 428, 430 (char. in key, descr., relation.); Rep. U. S. Comm. Fish. (1895), 1896: 282 (range).

Sardinella macrophthalmus Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 428, 430 (char. in key, descr., compar., range, synon. in part); Rep. U S. Comm. Fish. (1895), 1896: 282 (range); Jordan and Rutter, Proc. Acad. nat. Sci. Philad., *49*, 1898: 94 (ref., body depth, Kingston, Jamaica); Fowler, Proc. Acad. nat. Sci. Philad., *51*, 1900: 118 (Port Antonio, Jamaica; St. Martin and Santa Cruz, Lesser Antilles); Nichols, Bull. Amer. Mus. nat. Hist., *31* (18), 1912: 182 (capture, Havana Harbor, Cuba); Metzelaar, Trop. Atlant. Vissch., 1, 1919: 12, fig. 4 (synon., size, habitat, commerc. import., Curaçao; St. Eustatius); Breder, Bull. Bingham oceanogr. Coll., *1* (1), 1927: 12 (Glover Reef); Beebe and Tee-Van, Zoologica, N. Y., *10*, 1928: 41 (ref., field char., size, weight, range, distr., abund., capture, Port-au-Prince Bay, Haiti); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 68 (range, size); Zoologica, N. Y., *18* (3), 1934: 59 (Andros I., Bahamas); Parr, Bull. Bingham oceanogr. Coll., *3* (4), 1930: 3 (comments, Crooked Is., Bahamas only); von Ihering, Rev. Industr. Anim. São Paulo, 3, 1930: 229 (ref., diagn., Brazil).

Harengula pensacolae Goode and Bean 1879

Scaled Sardine, Sardine, Pilchard, Alewife, Fatback Minnow,
Shiner, Sprat, Sardina Escamuda, Sardina, Sardinha

Figure 97

Study Material. Numerous specimens, 39–149 mm SL, from Florida, the Gulf of Mexico, Bahamas, West Indies, Caribbean coast of Central and South America, and Brazil, USNM and UMIM.

Distinctive Characters. The absence of palatine teeth, the high number of gill rakers (30–40), the number of ventral scutes, the adherent scales, and the deeper body distinguish this species from all other western Atlantic forms.

Description. Proportional dimensions in per cent of standard length, and counts, based on 1,394 specimens, 39–149 mm SL.

Body: greatest depth 29.5–34.7; greatest width 14.0–15.6.

Caudal peduncle: least depth 10.6–11.4.

Head: length 28.0–31.5; depth at occiput 26.5–28.8

Snout: length 6.9–8.5.

Eye: diameter 9.0–12.0.

Interorbital: width 6.0–7.6.

Maxillary: length 12.7–14.3.

Dorsal fin: anterior height 18.1–20.3; length 23.6–25.3; length of base 16.4–19.0.

Anal fin: anterior height 6.3–7.1; length 18.9–21.9; length of base 14.3–16.0.

Pelvic fin: length 12.9–13.8.

Pectoral fin: length 21.8–24.1.

Distance from tip of snout to origin of: dorsal fin 42.7–45.8; anal fin 78.6–81.7; pelvic fin 53.6–55.6; pectoral fin 27.1–30.3.

Scales: transverse rows 39–43, usually 40–42; predorsal 11–14, usually 12 or 13.

Ventral scutes: 30–32; usually 31 in *p. majorina*; 28–31, usually 29 or 30, in other subspecies.

Gill rakers: 30–40; *p. majorina* with 30–37, usually 33–35; *p. caribbaea* with 31–37, usually 32–35; *p. pensacolae*, *p. cubana*, *p. floridana*, and *p. pinensis* with 34–40, usually 35–39.

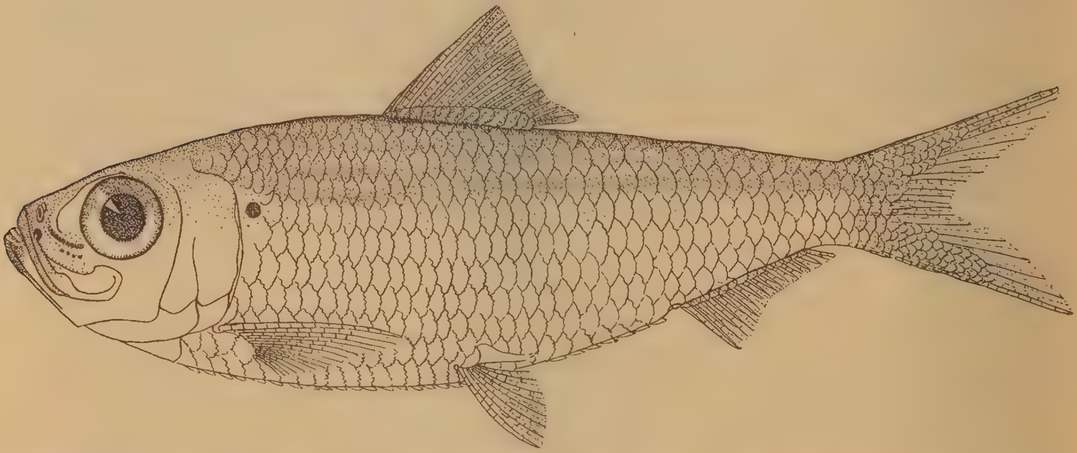

FIGURE 97. *Harengula pensacolae*, 104 mm SL, Province of Pinar del Rio, Cuba, type of *H. p. cubana*, USNM 132472. Drawn by Janet Ebeling, after Rivas (*108*).

PREDORSAL CONTOUR evenly and moderately convex, the POSTDORSAL CONTOUR more or less straight or very slightly convex from origin of dorsal to caudal fin; VENTRAL CONTOUR much more convex than dorsal contour, the body axis closer to dorsal than to pelvic fins. DORSAL fin originating nearer to tip of snout than to caudal base. PELVIC fin inserted about midway between insertion of pectoral and origin of anal, or nearer insertion of pectoral. PECTORAL fin inserted nearer to insertion of pelvic than to tip of snout.

Color. General coloration silvery, especially on the lower parts of the head and body; the opercular plates with iridescent or pearlish, metallic reflections. Back dark brownish or bluish gray. Body with dark, longitudinal streaks, more conspicuous on back. Humeral spot variable; conspicuous to faint. Tip of snout and mandible dusky. Upper sector of iris dusky. Fins colorless except caudal, which is somewhat pigmented at tip of lobes and along inner margin.

Size. The largest specimen examined measures 149 mm SL.

Range. Widely and generally distributed from Cape Canaveral, Florida, southward to Brazil, including the Gulf of Mexico, as discussed under *Variation*.

Variation. H. pensacolae has been subdived into five subspecies, namely *floridana*, *caribbaea*, *cubana*, *pinensis*, and *majorina*, the alternative characters of which were published in 1950 (*109*: key, 279): *floridana* Rivas 1950, a large-eyed form from the Florida Keys; *caribbaea* Rivas 1950, based on specimens with fewer gill rakers and a more slender body, from the Caribbean, and Central and South America—Nicaragua to Colombia, Jamaica, Hispaniola, and Puerto Rico; *cubana* Rivas 1950 and *pinensis* Rivas 1950, for those from northwestern Cuba and Isle of Pines, respectively; and *majorina* Storey 1938, for those from the Lesser Antilles, St. Lucia southward, and along the coast of South America from Venezuela to and including Brazil. These slightly different forms broadly intergrade with one another. As geographical separation of them would obviously be purely arbitrary, they are all united here under the specific name *pensacolae*.

Synonyms and References:

Harengula humeralis (not *Clupea humeralis* Cuvier 1829), Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 293 (descr., comments, local. in part; Guadeloupe, Rio de Janeiro to the West Indies; Brazil; Bahia; Surinam); Castelnau, Anim. Rares Amer. Sud, *2*, 1855: 56 (ref. in part, comments, Bahia, Brazil); Jordan, Proc. U. S. nat. Mus., *13*, 1891: 314 (Bahia, Brazil); Jordan and Thompson, Bull. U. S. Bur. Fish., *24*, 1905: 233 (abund., use as bait, Tortugas, Florida); Fowler, Proc. Acad. nat. Sci. Philad., *58*, 1906: 83, fig. 3 (color, Marquesas Keys and Hailer's Rock, Florida); *67*, 1915: 247 (Clearwater and Palm Beach, Florida).

Clupea humeralis (not of Cuvier 1829), Günther, Cat. Fish. Brit. Mus., *7*, 1868: 422 (synon., refs., descr., range, all in part); Cope, in part, Trans. Amer. philos. Soc., *14* (3), 1871: 483 (ref., St. Croix); Jordan, Proc. U. S. nat. Mus., *9*, 1887: 561 (synon. exclud., West Indies).

Harengula pensacolae Goode and Bean, Proc. U. S. nat. Mus., *2*, 1879: 152 (orig. descr., compar., Pensacola, Florida); Proc. U. S. nat. Mus., *2*, 1880: 343 (char., Clearwater Harbor, Florida); Jordan and Gilbert. Bull. U.S. nat. Mus., 16, 1882: 268 (descr.); Lönnberg, Ofvers Svensk. Vet. Akad. Forh., *51* (3), 1894: 114 (abund., use, St. Petersburg, Florida); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 387, 388 (char. in key, synon., ref., descr.; Florida; Trinidad); Fowler, Proc. Acad. nat. Sci. Philad., *71* (2), 1919: 129, 133, 144, 151 (Rio de Janeiro, Brazil; St. Martin, West Indies; St. Croix; habitat, behav., capture, Useppa I., Florida); *78*, 1926: 250 (size, color., Boca Grande, Florida); *80*, 1928: 456, 462 (Haiti; Puerto Rico); Proc. biol. Soc. Wash., *46*, 1933: 58 (size, Calcasieu Lake, Louisiana); Proc. Acad. nat. Sci. Philad., *92*, 1940: 2 (size, Boca Grande, Florida); Monogr. Acad. nat. Sci. Philad., 7, 1945: 104, 266 (synon., ref., size, use; Elizabeth City, N. Carolina; Florida locals.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, App. 10, 1930: 44 (range, Florida); Longley, Carneg. Instn. Yearbk., 31, 1932: 299 (nomencl.); Hubbs, Publ. Carneg. Instn. Wash., 457, 1936: 174 (char., nomencl., compar., Champoton, Campeche, Yucatán); Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 3, 7, 13, 15, 18, 21, 23, 25, 33, 50, figs. 1, 2, 4–11, 13 (relation., range, char., cf. *H. majorina*, descr., diagn., Florida and Texas locals.; Yucatán, México); Hildebrand *in* Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 11 (synon. of *H. macrophthalma*; gill rakers).

Clupea pensacolae Jordan, Proc. U. S. nat. Mus., *7*, 1884: 107 (abund., compar., color, Key West, Florida); Jordan and Swain, Proc. U. S. nat. Mus., *7*, 1884: 230 (color, relation., Cedar Keys, Florida); Jordan, Rep. U. S. Comm. Fish. (1885), App. 2, E (24), 1887: 36 (N. America); Henshall, Bull. U. S. Fish Comm., *9*, 1891: 385 (abund., range, Florida Keys; w. Florida).

Harengula arcuata (not *Clupea arcuata* Jenyns 1842), Jordan, Proc. U. S. nat. Mus., *12*, 1890: 645, 646 (char. in key, synon. in part; St. Lucia; Florida locals.); Henshall, Bull. U. S. Fish Comm., *9*, 1891: 373 (synon. in part, abund., Florida locals.); Evermann and Kendall, Bull. U. S. Fish Comm., *12*, 1894: 105 (compar., Texas locals.).

Sardinella humeralis (not *Clupea humeralis* Cuvier 1829), Jordan and Evermann, Bull. U. S. nat. Mus., *47* (1), 1896: 428, 431 (char. in key, descr., range, synon. and ref. in part, types of *H. pensacolae* design.); Rep. U. S. Comm. Fish. (1895), 1896: 283 (range, ref.); Fowler, Proc. Acad. nat. Sci. Philad., *51*, 1900:

118 (Port Antonio, Jamaica); Evermann and Marsh, Bull. U. S. Fish Comm. (1901), 1, 1902: 85 (char. in key, descr., synon., Puerto Rico locals.); Cockerell, Proc. biol. Soc. Wash., *23*, 1910: 63 (scales, Tampa, Florida); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 206 (Florida); Copeia, 24, 1915: 50 (Santo Domingo); Proc. Acad. nat. Sci. Philad., *69*, 1917: 128 (Colón, Panama); Metzelaar, Trop. Atlant. Vissch., 1, 1919: 11 (synon., size, doubt. poison., habitat, Curaçao; St. Eustatius).

Sardinella macrophthalmus (not *Clupea macrophthalma* Ranzani 1842), Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 182, pl. 9a (char. in key, synon. in part, descr., comments, range, Toro Point, Colón, Porto Bello, Panama).

Harengula sardina (not of Poey 1860), Fowler, Proc. Acad. nat. Sci. Philad., *89*, 1937: 309 (Port-au-Prince, Haiti).

Harengula majorina Storey, Stanf. Ichthyol. Bull., *1* (1), 1938: 7, 18, 21, 23, 25, 32, 42, 44, 50, 51, figs. 1, 8, 9, 17 (char., relation., compar., range, synon., diagn., comments, nomencl., West Indies; St. Lucia; Santos [São Paulo] Brazil); Fowler, Proc. Amer. philos. Soc., *82* (5), 1940: 745 (ill., Rio de Janeiro, Brazil); Hildebrand *in* Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 11 (comments); Fowler, Arqu. Zool. estad. São Paulo, *3* (6), 1941: 133 (ref., Brazil); Monogr. Acad. nat. Sci. Philad., 6, 1944: 144, 547, fig. 29 (synon., ref., descr., cf. *H. pensacolae*, St. Andrews I., local., ref., w. Caribbean).

Harengula macrophthalma (not *Clupea macrophthalma* Ranzani 1842), Gunter, Publ. Inst. Mar. Sci. Texas, *1* (1), 1945: 25, 128 (abund., capture, salinity, temp., size, Texas locals.).

Harengula pensacolae majorina Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 292–294, pl. 4, fig. 1 (synon., comments, compar., size, range).

Harengula pensacolae caribbaea Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 294–296, pl. 4, fig. 3 (synon., orig. diagn., comments, compar., size, range).

Harengula pensacolae pensacolae Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 281, 296–298, pl. 3, figs. 7, 8 (char. in key, synon., comments, compar., size, range).

Harengula pensacolae cubana Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 281, 298–301, fig. 40, pl. 5, fig. 1–3 (char. in key, orig. descr., compar., size, range, w. Cuba).

Harengula pensacolae floridana Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 281, 301, 302, pl. 4, fig. 2 (char. in key, orig. diagn., compar., Florida).

Harengula pensacolae pinensis Rivas, Proc. U. S. nat. Mus., *100* (3263), 1950: 281, 302, fig. 41, pl. 5, figs. 4–6 (char. in key, orig. diagn., compar., Isle of Pines, Cuba).

Genus *Sardinella* Cuvier and Valenciennes 1847

Spanish Sardines

By

Samuel F. Hildebrand

(continued)

Sardinella Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 261; genotype *S. aurita* Cuvier and Valenciennes, first designated by Gill, Proc. Acad. nat. Sci. Philad., 1861; 35.

Generic Synonym:

Sardinia Poey, Memorias, *2*, 1860: 311; genotype by monotypy, *Sardinia pseudo-hispanica* equals *S. anchovia* Cuvier and Valenciennes.

Characters. BODY quite slender, compressed, its greatest depth equal to or less than length of head. BONY SCUTES rather weak, 32–34 along moderately sharp edge of chest and abdomen. SCALES thin, moderately adherent, with one to several vertical grooves. Vertical part of anterior CLAVICULAR MARGIN (cleithrum) with two membranous projections or lobes, a definite concavity between them (Fig. 100). OPERCLE without radiating grooves. MOUTH moderately small. MAXILLARY generally extending a little beyond anterior margin of eye. UPPER JAW without a median notch. LOWER JAW projecting slightly beyond the upper. TEETH absent in upper jaw; several in anterior part of lower jaw; minute teeth also on palatines, pterygoids, and tongue but absent on vomer. GILL RAKERS numerous, close-set, increasing in number with age, difficult to count (ftn. 47), about 70–130 on lower limb of first arch in adults; rakers on upper limb not overlapping those on lower limb, decreasing gradually in length toward anterior part of lower limb. DORSAL with 17–19 rays, the last one not produced. ANAL with 16–20 rays, the last two notably enlarged, finlet-like. PELVIC fin inserted under base of dorsal, almost constantly with 9 rays. PECTORAL fin without a free axillary process, the fin lying in a slight depression.[45] VERTEBRAE about 45–47.

Remarks. Confusion in regard to the relationship of *Sardinella* Cuvier and Valenciennes, *Sardina* Antipa,[46] and *Sardinia* Poey has existed and even now has not been cleared up completely. This relationship has been discussed by Regan (*106*: 377), Jordan (*70*: 46), Hubbs (*61*: 261–265), and Longley (*87*: 5), and apparently the conclusion may be reached that *Sardinella* differs from *Sardina* in the absence of radiating grooves (or ridges) on the opercle and in the presence of two membranous lobes on the vertical edge of the clavicular margin (cleithrum). Further, it appears that *Sardinia*

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[45] The generic description is based wholly on American specimens, as adequate material from the other side of the Atlantic is not available.

[46] *Sardina* Antipa 1905 appears to be a synonym of *Arengus* Cornide 1788 (see *23*: 43).—G. S. M.

Poey is a synonym of *Sardinella* and that *Clupanodon* has no American representative. As the last ray of the dorsal in *Clupanodon* is prolonged, its relationship is with *Opisthonema*, *Dorosoma*, and *Signalosa* (here a synonym of *Dorosoma*) rather than with *Sardinella*. In his discussion, Hubbs (*61*: 261–265) set up a new genus, *Sardinops*, for the sardines of the Pacific and South Africa. This genus differs from *Sardinella* principally in the absence of the fleshy lobes on the cleithrum, in the presence of oblique ridges on the opercle, and in the overlapping gill rakers, those on the upper arch extending downward over those on the lower limb.

Species. The species of this genus remain somewhat obscure. Among the three recognized as coming within the scope of this work, *pinnula* is definitely distinct according to the specimens at hand; however, specimens from Cuba and Jamaica, not in good condition, seem to be more or less intermediate between *anchovia* from the Atlantic coast of the United States and *brasiliensis* from Port-of-Spain, Trinidad, and southward. Such specimens also are included among collections from Rio de Janeiro, Brazil. More material and further study will be required to determine the exact relationship.

The number of gill rakers on the first arch seems to be the best diagnostic character, but the rakers are so numerous, fine, and close-set that they are exceedingly difficult to count accurately.[47] Consequently, the use of this character requires much time and patience. Its ready use is limited further by the increase in number with age and growth, making it necessary to compare the number present in specimens of nearly equal size.

Other characters having limited diagnostic value are depth of body, size of head, eye, and mouth, development of the palatine and pterygoid teeth, the position of dorsal and pelvic fins, and length of pectoral fin. The color, so far as can be determined from the preserved specimens at hand, is rather uniform among the species recognized. The species are carnivorous, occur in schools, and are marine in habitat.

Range. Cape Cod, Massachusetts, to southern Brazil, but not yet known from México to Colombia. They occur also off Bermuda, Cuba, Jamaica, Trinidad, in the eastern Atlantic, and in the Indo-Pacific (*106*: 377).

Key to Species of the Western Atlantic

1a. Distance from margin of snout to origin of dorsal about equal to 33 % of TL, 41–43.5 % of SL; eye equal to, or usually shorter than, snout, its diameter 5.3–7.3 % of SL; snout 6.0–7.6; gill rakers about 70–100 on lower limb of first arch (fewer in young); pectoral fin failing to reach base of pelvic by a distance nearly or quite equal to length of snout and eye.

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[47] It was found necessary to remove the gill rakers from the arch to make an accurate count. The arch was severed from the body near the base of the rakers, the membrane was freed from the bony arch at one end, the loosened end was grasped with forceps, and a gentle pull then freed the membrane with the rakers intact. In a watch glass under low power of a binocular, the rakers could be separated by ones, twos, or threes, an accurate count thus being obtained. The counts made previously either with the arch in its natural position or after removal from the body ran much too high, the error being greatest among those with the highest number of rakers.

2a. Greatest thickness of body exceeding half its depth; head length greater than depth of body, 24–26 %, and its depth 18–22 % of SL, the depth at vertical from crossgroove at occiput 15.5–17.5 % of SL; pectoral failing to reach base of pelvic by a distance somewhat shorter than snout and eye, leaving 6 or 7 rows of scales exposed between its tip and base of pelvic, its length 16–18.5 % of SL. *pinnula* T. H. Bean 1912, below.

2b. Greatest thickness of body generally less than half its depth; head length about equal to greatest depth of body, 22.3–27.2, and its depth 21–26.9 % of SL, the depth at vertical from crossgroove at occiput 17.6–19.7 % of SL; pectoral failing to reach base of pelvic by a distance generally equal to length of snout and eye, leaving 6–8 rows of scales exposed between its tip and base of pelvic, its length 15–17.6 % of SL.
anchovia (Cuvier and Valenciennes) 1847, p. 401.

1b. Distance from margin of snout to origin of dorsal notably greater than 33 % of TL, 44–47.5 % of SL; eye equal to or longer than snout (rarely slightly shorter), its diameter 6.9–7.9 % of SL; snout 7.3–8.15; gill rakers about 110–130 on lower limb in specimens 70 mm and upward (fewer in young); pectoral fin failing to reach base of pelvic by a distance about equal to diameter of eye.
brasiliensis (Steindachner) 1879, p. 407.

Sardinella pinnula T. H. Bean 1912

Bermuda Anchovy

Figure 98

Study Material. A total of 41 specimens with caudal fins broken, 74–135 mm SL, including five specimens of type material, 93–135 mm TL, 74–114 mm SL; no holotype designated; all specimens from Bermuda.

Distinctive Characters. This species is very close to the species herein recognized as *anchovia*, from which it differs in the more elongated and more robust body and especially in the lower head.

Description. Proportional dimensions in per cent of standard length, and counts, based on 24 study specimens within the length ranges given above.

Body: depth 18–22.
Caudal peduncle: depth 6.4–8.2.
Head: length 24–26; depth 15.5–17.5.
Snout: length 7.0–7.6.
Eye: diameter 5.9–7.0.
Interorbital: width 4.2–5.2.
Maxillary: length 9.2–10.5.
Anal fin: length of base 13–16.
Pelvic fin: length 9.2–10.7.
Pectoral fin: length 16–18.5.
Distance from snout to origin of: dorsal 41–42.5.

Scales: *ca.* 43–47, often lost from preserved specimens.
Ventral scutes: 32–34.
Fin rays: dorsal 17–19; anal 15–18; pectoral 16 or 17.
Vertebrae: 46–47 (3 specimens).

BODY with greatest thickness exceeding half of depth, its greatest depth 4.5–5.5 in SL; ventral outline notably more strongly convex than dorsal outline. CAUDAL PEDUNCLE slender, its depth 3.0–3.75 in head.

SCALES lost in most specimens, apparently not different from those of *S. anchovia*; 6 or 7 rows of scales exposed between tip of pectoral and base of pelvic. VENTRAL SCUTES not strong, 18 or 19 in advance of pelvics and 14 or 15 behind them.

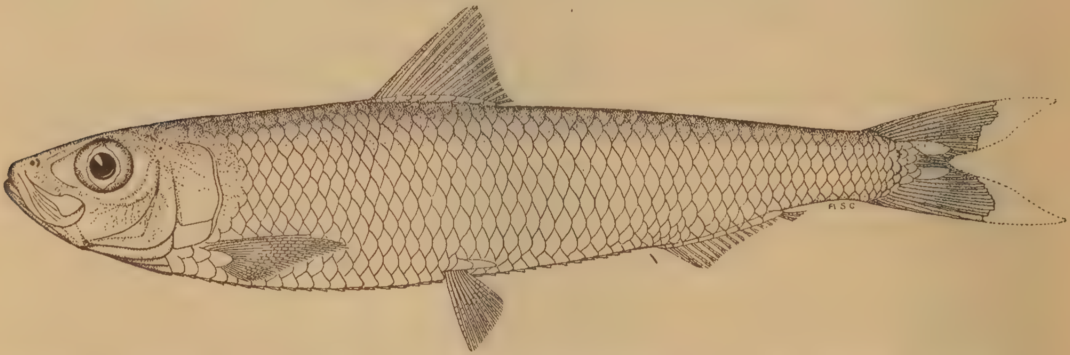

FIGURE 98. *Sardinella pinnula*, about 124 mm TL (caudal damaged), 100 mm SL, Bermuda, USNM 21252. Drawn by Ann S. Green.

HEAD small, slender, 3.85–4.15 in SL, its depth at vertical from crossgroove at occiput 5.0–6.1 in SL. SNOUT moderately long, 3.2–3.4 in head. EYE small, its diameter definitely shorter than snout, 3.55–4.15 in head. INTERORBITAL 4.7–5.9. CHEEK longer than deep. MAXILLARY rather broadly rounded posteriorly, scarcely reaching vertical from anterior margin of pupil, 2.3–2.6 in head. MANDIBLE projecting moderately, its margin within mouth rising rather gradually, without a definite angle. GILL RAKERS long, slender, close-set, difficult to count, those at angle about as long as eye, the serrations on inner edge of rakers minute; the rakers increasing in number with age: about 75 on lower limb of first arch in specimens about 85 mm long, about 90 in those about 100 mm SL (gill rakers removed for counting). TEETH as in *S. anchovia.*

DORSAL fin rather high anteriorly, its margin definitely concave, its longest ray generally reaching to or beyond tip of last ray if deflexed, its origin rather nearer to margin of snout than to vertical from base of last anal ray, its distance from margin of snout 2.3–2.4 in SL; the base with a very narrow sheath of scales. CAUDAL forked; broken in all specimens at hand. ANAL fin much lower than dorsal, with a slight lobe anteriorly, its last two enlarged rays nearly as long as the longest ones in anterior lobe of fin, its origin about equidistant between insertion of pelvic and base of caudal, its base 1.55–1.9 in head. PELVIC fin reaching a little more than a third of the way to origin of anal, inserted about equidistant between base of pectoral and origin of anal, 2.4–2.75 in head; the axillary process reaching about to beginning of distal third of fin. PECTORAL fin rather short, not falcate, its length 5.4–6.25 in SL, 1.35–1.55 in head, failing to reach base of pelvic by a distance generally equal to snout and about half of eye.

Color. Specimens at hand badly faded; apparently not different from *S. anchovia.* Described as "steel blue above, silvery below, iridescent. Head, in spirits with golden tints; no opercular spot" (*9*: 122).

Size. This, the Anchovy of Bermuda, reaches a length of 6 or 7 inches (*11*: 35). The average length of those observed by Goode was about 5 inches (*42*: 69).

Habits. Like the others of the genus, this little sardine schools, usually in the offshore waters, and tends to come inshore in large schools "about sunrise or sunset" (*4*: 112).

Commercial Importance. This little Sardine was sold "in quantities along the quay" in March 1872, presumably for human consumption (*42*: 69). Barbour said that in 1903 it was seined regularly for bait in Hamilton Harbor and Flatts Inlet (*4*: 112). Although it was reported as "uncommon close in shore but very abundant in mid-water in greater depths" (*11*: 35), it was not stated that it is either eaten by man or used as bait. A small fish occurring in the abundance indicated must be of considerable value as forage for larger predatory foodfishes.

Range. Known only from Bermuda.

Synonyms and References:

Sardinella anchovia Goode (not of Cuvier and Valenciennes), Bull. U. S. nat. Mus., 5, 1876: 69 (Bermuda, average size); Barbour, Bull. Mus. comp. Zool. Harv., *46* (7), 1905: 112 (distr.; in part not *pinnula*; Hamilton Harbor, Bermuda); Beebe and Tee-Van (in part not of C. and V.), Field Bk. Shore Fish. Bermuda, 1933: 35 (field char., diagn., distr.); Beebe and Tee-Van (not of C. and V.), Zoologica, N. Y., *13* (7), 1933: 135 (*S. pinnula* synon. with *S. anchovia*); Hollister (not of C. and V.), Zoologica, N. Y., *21* (4), 1936: 186 (caudal skel.).

Sardinella pinnula T. H. Bean, Proc. biol. Soc. Wash., *25*, 1912: 122 (orig. descr.; type local. Bermuda; types USNM 74086; local name).

Sardinella anchovia (Cuvier and Valenciennes) 1847

Spanish Sardine, Sardina de España, False Sardine, Sardina, Bang

Figures 99, 100

Study Material. Many specimens, from Woods Hole, Massachusetts; Blue Point Cove, Long Island, New York; Beaufort, North Carolina; and Tortugas, Florida. Several additional specimens from Cuba, Jamaica, and Rio de Janeiro, Brazil, apparently belong to this species also.

Distinctive Characters: See *Relationship* and *Variation.*

Description. Proportional dimensions in per cent of standard length, based on 32 specimens, 90–155 mm TL, 70–127 mm SL.

Body: depth 21–26.9.
Caudal peduncle: depth 7.7–10.
Head: length 22.3–27.2; depth 17.6–19.7.
Snout: length 6.0–7.5.
Eye: diameter 5.3–7.3.
Interorbital: width 4.2–5.3.
Maxillary: length 8.75–11.
Anal fin: length of base 13.7–16.
Pelvic fin: length 8.5–11.
Pectoral fin: length 15–17.6.
Distance from snout to origin of: dorsal fin 40–43.5.

Scales: about 41–46, often lost from preserved specimens.
Ventral scutes: 32–34.
Fin rays: dorsal 17–19, occasionally 20; anal 16–18; pectoral 15 or 16.
Vertebrae: 45–47 (7 specimens).

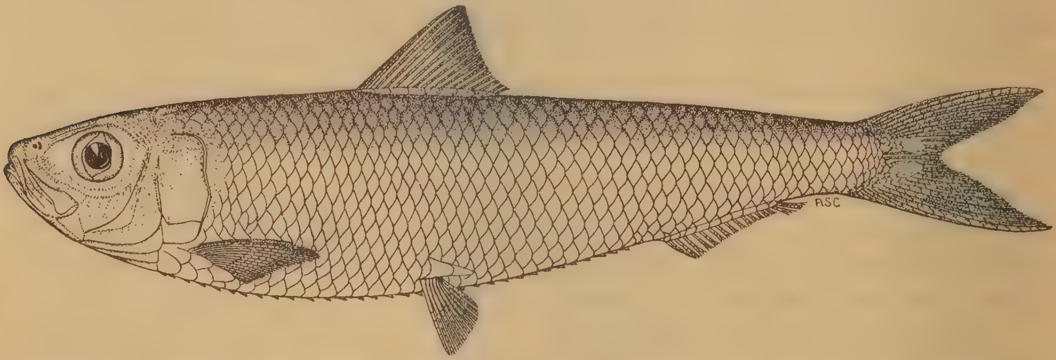

FIGURE 99. *Sardinella anchovia*, about 120 mm TL, 95 mm SL, Woods Hole, Massachusetts, USNM 90233. Drawn by Ann S. Green.

BODY rather strongly compressed, its greatest thickness generally less than half of its depth, its greatest depth 3.7–4.75 in SL; ventral outline notably more strongly convex than dorsal outline. CAUDAL PEDUNCLE slender, moderately compressed, its depth 2.5–3.6 in head.

SCALES moderately adherent, those from middle of side below anterior rays of dorsal scarcely deeper than long, with 3 or 4 more or less complete vertical grooves, the margin of these scales scarcely indented but scales on back in front of dorsal fin definitely indented; 6–8 rows of scales exposed between tip of pectoral and base of pelvic fin. The pair of modified scales at nape small, shorter than eye. VENTRAL SCUTES small, 18 or 19 in front of pelvic fins and 14 or 15 behind them.

HEAD 3.65–4.35 in SL, its depth at vertical from crossgroove at occiput 4.95–5.1. SNOUT 3.0–3.9 in head, its margin without a median notch. EYE shorter than snout, 3.4–4.5 in head. INTERORBITAL bone (over middle of eye) 4.3–6.0. CHEEK longer than deep. MAXILLARY rounded posteriorly, reaching to or a little beyond vertical from anterior margin of pupil, 2.3–2.7 in head. MANDIBLE projecting only slightly, its margin without mouth rising rather gradually without a definite angle. GILL RAKERS long, slender, close-set, those at angle about as long as eye, the serrations on inner edge minute, the rakers increasing in number with age, difficult to count; about 55–60 on lower limb of first arch in specimens 37–44 mm, about 70–75 in examples 70–80 mm, and 85–100 in specimens 105–125 mm SL (gill rakers removed from arch for counting). TEETH absent on upper jaw; some fine points on margin of maxillary; lower jaw with a few small teeth anteriorly on each side of a median interruption; a few minute teeth on palatines, pterygoids, and tongue.

DORSAL fin only moderately elevated anteriorly, its margin somewhat concave, its longest ray usually failing to reach the tip of last one if deflexed, its origin about equidistant between margin of snout and vertical from middle of base of anal, its distance from the margin of snout 2.3–3.5 in SL; its base with a very narrow sheath composed of a single row of elongated scales, the posterior ones with a free lower margin. CAUDAL fin rather deeply forked, the lower lobe slightly the longer, without scales except for a few modified ones on its base. ANAL fin much lower than dorsal, its last two rays notably enlarged and scarcely shorter than the longest ones in anterior lobe of fin, its origin about equidistant between the insertion of pelvic fin and base of caudal, its base 1.45–1.8 in head; a sheath of scales at base somewhat broader than that of dorsal. PELVIC fin with margin scarcely convex when spread, reaching a little more than halfway to origin of anal, its shortest ray about 75 % of the length of longest ray, the fin inserted about equidistant between base of pectoral and origin of anal, 2.1–3.0 in head; the axillary process reaching to or beyond midlength of fin. PECTORAL fin scarcely falcate, failing to reach base of pelvic fin by a distance nearly equal to, or quite equal to, length of snout and eye, its length from base of upper ray to tip of fin 5.7–6.6 in SL, 1.35–1.6 in head.

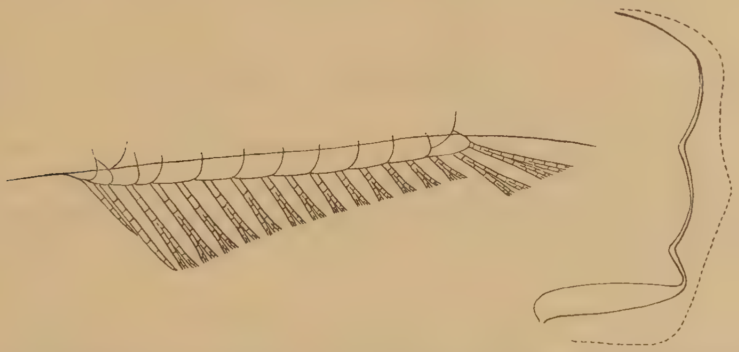

FIGURE 100. *Sardinella anchovia.* LEFT, anal fin showing last two large rays; RIGHT, left-hand rim of pectoral girdle (cleithrum), showing two lobes underneath free edge of gill cover; both from specimen in Fig. 99. Drawn by Ann S. Green.

Color. Bluish black above, changing rather abruptly to bright silvery at level of upper margin of eye. Head and especially snout with many dusky punctulations; dorsal and caudal rays with numerous dark dots, these especially crowded on distal parts of longest rays of dorsal, giving the lobe a blackish appearance when folded; the other fins plain, translucent, except for dark dots on 2 or 3 of the uppermost rays of the pectoral.

Live fish have been described as very dark blue above and silvery on the side and below (*87*: 7).

Size. The largest specimen at hand, with damaged caudal fin, is about 163 mm (6.5 in.) TL and 130 mm SL. However, a length of eight inches has been reported, though the usual length, judging from the examples at hand, probably is about four or five inches.

Development and Growth. The smallest specimens at hand are 26 mm SL (32 mm TL), taken at Tortugas, Florida, and 31–44 mm SL, from Beaufort, North Carolina, taken on June 30, 1913. These young, as is usual among Clupeidae, are notably more slender than their adults; the depth in the smallest ones (26–31 mm SL) is contained 5.1–6.2 times in SL; at about 60 mm SL the fish have attained near adult proportions.

As already noted (p. 402), the gill rakers increase with age and growth: about 50–60 on the lower limb of specimens 37–44 mm, 70–75 at 70–80 mm, and 85–100 at 105–125 mm SL. The smallest reported for Tortugas, up to 32 mm length, had only "22 or 23 gill rakers" (*87*: 8), and the smallest now at hand, 26 mm SL, has about 36 gill rakers on the lower limb. These data, then, indicate that the greatest proportional increase in the number of rakers takes place in the young under about 70 mm SL.

Spawning. Although Longley did not give the collection dates for the young 26-mm fish referred to above and for young "up to 32 mm in length" reported for Tortugas (*87*: 8), it is known that he worked at Tortugas only from about the last half of June to the early part of September. As such small young probably had not strayed far from the place where they were hatched, it may be assumed that at least some spawning takes place there during the summer.

Habits. These fish, like most of the herrings, run more or less in schools. In the fall of the year at Woods Hole, Massachusetts, the fish occur irregularly and in varying degrees of abundance (*120*: 91). Since these warm-water fish are not permanent residents there and since only adults seem to have been taken, it is surmised that they may migrate northward in the Gulf Stream. The fish in the vicinity of Tortugas, at least, seem to be most common some distance offshore where the water is 10–20 fms. deep, although they do come inshore (*87*: 7). Similar habits have been reported for the Bermuda sardine (*11*: 35).

Food. Numerous copepods were found in the alimentary canal of specimens taken at Woods Hole (*85*: 438). The numerous close-set gill rakers provide an effective straining apparatus for extracting minute organisms from the water. Therefore, an almost exclusively planktonic diet is assumed.

Enemies. Examples of this species were reported among the refuse on the tern rookery, Bird Key, Tortugas, Florida (*87*: 8). Other water birds and many predatory fish no doubt also feed on this sardine.

Parasites. The trematode, *Distomum appendiculatum*, was reported for the intestinal tract of specimens from Woods Hole, Massachusetts (*85*: 438), and the parasitic copepod, *Bomolochus eminens* Wilson, was found on the gills of specimens taken at Tortugas (*134*: 370).

Relationship. Longley discovered that the type material of *S. anchovia*, from Rio de Janeiro, Brazil, in Paris, consists of two species that are separable by the number of gill rakers on the lower limb of the first arch (*87*: 7); he reported that one example, 116 mm SL, has 105 rakers, while the other four, 114–148 mm SL, have 160–178. Although Longley's counts are probably not entirely accurate, the difference may be accepted as valid. Since the specimen with the smallest number of rakers was mentioned first in the original description, Longley accepted it as the type of *S. anchovia*; this specimen was taken by M. Delalande, the other four by M. d'Orbigny and M. Gay; Longley assigned the other four specimens to *brasiliensis* (p. 409) because they had many more rakers and a more strongly compressed body than the above-mentioned type of *anchovia*, specimens of approximately equal length having been considered.

The number of gill rakers given for this "type" by Longley (105) corresponds approximately to the number counted in the specimens herein described (85–100), and since Longley gave no other character that disagrees with these specimens, *anchovia* has been accepted as available for this species, but with considerable doubt. This doubt results from an apparent absence among many Brazilian specimens of fish that have as low a gill raker count as the northern specimens of *anchovia* herein described. Indeed, there are slender specimens from Brazil with fewer rakers than in *brasiliensis*, as herein understood, but the raker counts and the relative pectoral fin length are somewhat intermediate between those for *anchovia* of the eastern United States coast and the *braziliensis* from Trinidad and elsewhere. Therefore, they may be at least subspecifically distinct from eastern United States specimens described here. If they should prove to be specifically distinct, then the South American species would stand as *anchovia* while Poey's name, *pseudo-hispanica*, may be available for the northern species. However, this cannot be definitely determined from the material at hand. In fact, specimens from Cuba, presumably identified as *pseudoharengus* by Poey, seem to belong to *brasiliensis* rather than to *anchovia*.

In the northern part of the range, *S. anchovia*, most frequently listed in the past as *Clupanodon pseudohispanicus*, has frequently been confused with *Clupea harengus* (the common Atlantic herring). This has led to some confusion, as pointed out by Longley (*87*: 6) and others. The two species, indeed, resemble each other superficially in having approximately an equally elongated body, but *anchovia* is easily distinguishable from *C. harengus* by the more anterior position of its dorsal fin, absence of vomerine teeth, fewer ventral scutes, fewer vertebrae, a smaller eye, and the enlargement of the last two anal rays. These differences are all shown in detail in the descriptions.

S. anchovia of the American coast probably was incorrectly synonomized with *S. aurita* of Europe and elsewhere by Regan in his revision of the genus (*106*: 378). This tentative conclusion was reached by Longley after he had examined the type material of both species in Paris (see above). From Longley's data it appears that *aurita* grows larger than any American representative of the genus and that it is somewhat intermediate between *anchovia* and *brasiliensis* (as herein understood) in the number of gill rakers. Based upon two specimens of *aurita* from the Bay of Naples, Italy, the body is more slender than that of *anchovia* (comparing specimens of equal size), the pectoral fin is somewhat shorter, and the ventral scutes are slightly more numerous, 35 and 37. However, the exact relationship must remain undetermined until more adequate material becomes available for comparison.

S. anchovia and the species herein designated *brasiliensis* are represented by close relatives in Cuba and Jamaica even though other specimens, such as those from Woods Hole, Massachusetts, and from Port-of-Spain, Trinidad, differ rather prominently. However, the material from Cuba and Jamaica is too meager and too indifferently preserved to determine the exact relationship (see *Relationship*, pp. 405, 409).

Variation. The increase in body depth and the number of gill rakers have already been noted (pp. 398, 399); examples of equal size also vary to a considerable degree in these respects. There is variation also in the position of the dorsal and pelvic fins, relative size of eye, shape of dorsal, and length of pectoral (see *Description*, p. 401).

Commercial Importance. These fish are not common enough regularly north of the Florida Keys to be of commercial importance, but at Tortugas, Florida, particularly offshore in 10–20 fms., they are common (*87*: 7, 8). Longley reported that terns fed upon them. Undoubtedly they are also preyed upon by predacious foodfishes. They were observed in the market in Havana, Cuba, in February and March 1912, by Nichols, who said: "Abundant in the Havana market" (*98*: 180).

Range. Woods Hole, Massachusetts, to the Florida Keys, and probably southward to southern Brazil. The specimens from the Gulf of Mexico coast seem to be *brasiliensis*. Apparently they do not occur regularly north of Florida. In the vicinity of Woods Hole, where they appear only during autumn (*124*: 741), they were abundant in the fall of 1892 at least. It has been said that they are generally common in the West Indies region.

Synonyms and References:

Sardinella anchovia Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 269 (orig. descr.; type local. Rio de Janeiro, Brazil); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 429 (descr., range); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 183 (synon., descr., range); Breder, Field Bk. Mar. Fish. Atl. Cst., 1929: 67, fig. (abund., food, size); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 201 (distr., diagn., remarks, habits); Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 7 (synon., relation. with *Clupea harengus*, *S. brasiliensis*, and *S. aurita*, descr., Tortugas, Florida, range).

Clupea anchovia Günther, Cat. Fish. Brit. Mus., *7*, 1868: 421 (diagn., range).

Clupea pseudohispanicus Kendall and Smith (in part, *Clupea harengus*), Bull. U. S. Fish Comm. (1894), *14*, 1895: 17 (distr., descr., probably two or more species; cf. specimens from diff. locals.).

Clupanadon pseudohispanicus Jordan and Evermann (in part *Clupea harengus*), Bull. U. S. nat. Mus., 47 (1), 1896: 423 (descr., after Kendall and Smith; relation. to European species); Smith, Bull. U. S. Fish Comm. (1897), *17*, 1898: 91 (Woods Hole, Massachusetts; usually found with young *Clupea harengus*); Linton, Bull. U. S. Fish Comm. (1899), *19*, 1901: 438 (food, parasites, Woods Hole, Mass.); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 84 (descr., distr., Puerto Rican names, size, synon.); Wilson, Proc. U. S. nat. Mus., *39*, 1911: 370 (parasitic copepod, *Bomolophus eminens*, on gills); Nichols, Bull. Amer. Mus. nat. Hist., *31* (18), 1912: 180 (abund. Havana, Cuba, market); Sumner, Osburn, and Cole, Bull. U. S. Bur. Fish. (1911), *31* (2), 1913: 741 (refs., Woods Hole, Mass., food, parasites); Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 180 (synon., descr., distr.); Beebe and Tee-Van (in part *S. brasiliensis*), Zoologica, N. Y., *10* (1), 1928: 39 (refs., field char., discus.).

Sardinella aurita Regan (in part *S. brasiliensis*), Ann. Mag. nat. Hist., (8) *19*, 1917: 378 (synon., in part not this species; descr. in part, range); Jordan (in part not of C. and V.), Manual Vert. Anim. NE U. S., ed. 13, 1929: 41 (diagn., range); Jordan, Evermann, and Clark (in part not of C. and V.), Rep. U. S. Comm. Fish. (1928), 2, 1930: 43 (range, synon.).

Sardinia anchovia Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 43 (range, synon.).

Sardinia pseudo-hispanica Howell, Bull. Mus. comp. Zool. Harv., *82* (2), 1938: 171 (*S. pseudo-hispanica* Poey to synon. of *S. anchovia* C. and V.; cotypes).

Doubtful References:

Sardinia pseudo-hispanica Poey, Memorias, Cuba, *2*, 1860: 311 (orig. descr.; type local. Cuba; cotypes Nos. 17768 and 17771; local name).

Clupea pseudohispanica Günther, Cat. Fish Brit. Mus., *7*, 1868: 442 (descr. after Poey).

Sardinella brasiliensis (Steindachner) 1879

Sardinia, Sardinia de España, Spanish Sardine, Sardinha Verdadeira

Figure 101

Study Material. Numerous specimens, 82–129 mm TL, 64–98 mm SL, from Port-of-Spain, Trinidad. Also specimens for comparison, from Island of Marguerita, Venezuela; Cuba; Jamaica; Palmetto Key, and Pensacola, Florida; and many from Rio de Janeiro, Brazil, not used in preparing the description, since they are extralimital and may prove to be at least subspecifically distinct; all in the USNM collections.

Distinctive Characters. See *Relationship.*

Description. Proportional dimensions in per cent of standard length, and counts, based principally on study specimens, 64–98 mm SL.

Body: depth 22.4–26.9.
Caudal peduncle: depth 7.5–9.5.
Head: length 25.3–28.7; depth 18.7–22.
Snout: length 7.3–8.15.
Eye: diameter 6.9–7.9.
Interorbital: width 4.9–5.7.
Maxillary: length 10.7–11.7.
Anal fin: length of base 15.1–16.5.
Pelvic fin: length 9.9–11.2.
Pectoral fin: length 17.3–19.5.
Distance from snout to origin of: dorsal 44–47.5.
Scales: 42–47.
Ventral scutes: 32–34.
Fin rays: dorsal 17 or 18; anal 18–20; pectoral 15 or 16.
Vertebrae: 46 (4 specimens).

BODY slender, strongly compressed, its greatest thickness about half of its depth, its greatest depth generally at dorsal origin, 3.7–4.45 in SL; ventral outline much more strongly convex than dorsal outline. CAUDAL PEDUNCLE strongly compressed, its depth 2.9–3.75 in head.

SCALES only moderately adherent; those on middle of side below base of dorsal scarcely deeper than long, with 3 or 4 partly incomplete vertical grooves, the margin membranous and scarcely indented, but those on back in front of dorsal fin with definitely indented margin, and no vertical grooves; 4 or 5 rows of scales exposed between tip of pectoral and base of pelvic. The pair of modified scales at nape shorter than eye. VENTRAL SCUTES not prominent, 18 or 19 in front of pelvic fins and 14 or 15 behind them.

HEAD with length rather exceeding greatest depth of body, 3.5–3.95 in SL, its depth at vertical from slight crossgroove at occiput 4.55–5.35 in SL. SNOUT rounded, its margin without a median notch, 3.4–3.8 in head. EYE with diameter equal to, or a little longer than, snout (rarely slightly shorter), 3.4–3.8 in head. INTERORBITAL (over middle of eye) 4.8–5.8. CHEEK longer than deep. MAXILLARY broadly rounded posteriorly, reaching nearly or quite to vertical from anterior margin of pupil, 2.3–2.5 in head. MANDIBLE projecting slightly, its margin within mouth rising rather gradually without forming a definite angle. GILL RAKERS long, very slender, extremely close-set, very difficult to count, the longest about as long as eye, the serrations on inner edge extremely minute; the rakers increasing in number with age and growth: 82 and 83 in specimens 64 and 68 mm SL, 116 in an 89-mm specimen, and 130 and 132 in specimens 91 and 93 mm SL (gill rakers removed for counting). TEETH absent in upper jaw; some fine points present on margin of maxillary; lower jaw with a row of 5–7 very small teeth anteriorly on each side of a median interruption; very small granular teeth present on palatines, pterygoids, and tongue.

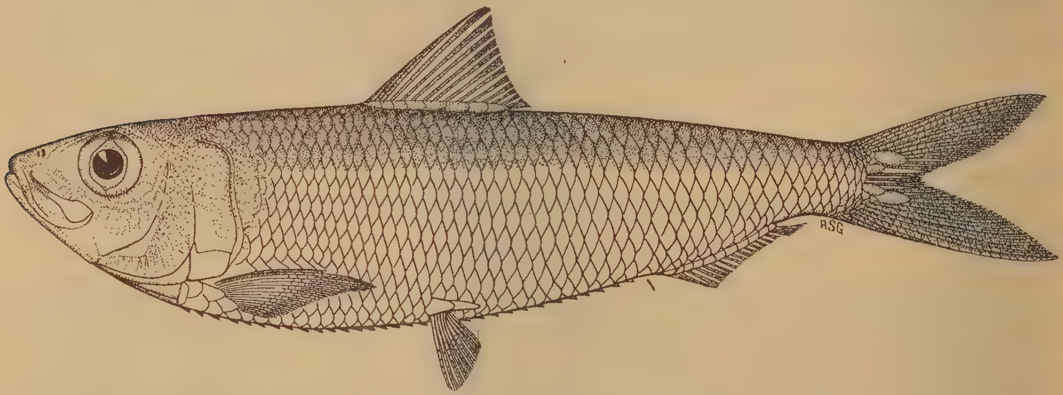

FIGURE 101. *Sardinella brasiliensis*, 122 mm TL, 94 mm SL, Port-of-Spain, Trinidad, USNM 124317. Drawn by Ann S. Green.

DORSAL fin moderately elevated anteriorly, its margin definitely concave, its longest rays usually failing to reach the tip of last ray if deflexed, its origin a little nearer to margin of snout than to vertical from last ray of anal, its distance from margin of snout 2.15–2.25 in SL; the base of fin with a very narrow sheath composed of a single row of elongated scales, the posterior ones having a free lower margin. CAUDAL fin rather deeply forked, the lower lobe slightly the longer; no small scales, but a few large modified ones on base of fin (Fig. 101). ANAL much lower than dorsal, its last two rays considerably enlarged and scarcely shorter than the longest ones in anterior lobe of fin, its origin generally a little nearer to base of caudal than to base of pelvic, its base 1.7–1.85 in head; a moderately broad sheath of scales at base. PELVIC fin with margin slightly convex when spread, reaching notably less than halfway to origin of anal, its shortest ray about 75 % of the length of the longest one, the fin inserted equidistant between base of pectoral and origin of anal, or a little nearer to the former, 2.5–2.8 in head; the axillary process reaching to or beyond midlength of fin. PECTORAL fin slightly falcate, generally failing to reach base of pelvic fin by a distance nearly equal to diameter of eye, its length from base to tip of longest ray 5.1–5.8 in SL, 1.4–1.55 in head.

Color. Bluish black above, changing abruptly to bright silvery at level of upper margin of eye. Region of shoulder, upper surface of head, snout, and mandible with dusky punctulations. Dorsal and caudal more or less dusky, the lobe of the dorsal dusky when folded, the dusky appearance being caused by dark dots on the rays (missing on inter-radial membranes); the other fins plain, translucent, except for dark dots on one or two uppermost rays of pectoral. Peritoneum black.

Size. The largest example included in the collections examined is 180 mm (7.2 in.) TL, 145 mm SL. However, examples 230 mm (9.2 in.) long have been reported (*25*: 189).

Development. No young definitely identified as this species are included in the collections examined, the smallest being 82 mm TL, 64 mm SL. Nevertheless, it is evident that the remarks on the development of young *S. anchovia* (p. 404) also apply to this species, as the smallest examples are the slenderest and have the fewest gill rakers on the lower limb.

Food. The food of this species has not been listed. However, the very numerous close-set gill rakers and the stomach with heavy walls and numerous pyloric coeca suggest a diet consisting of plankton.

Relationship. This species has been here designated as *brasiliensis* principally because of Longley's discovery that the type material of *anchovia*, in Paris, consisted of two species (*87*: 7), as stated in the account of *anchovia* (p. 405). Accordingly, Longley assigned the specimens with the more numerous gill rakers to *brasiliensis*, which may be correct, but positive proof is lacking, as the original description of *brasiliensis* gives neither the number of rakers nor any other diagnostic character as herein understood. The specimens (or species) with the greater number of rakers were compared with one identified as "*Clupea brasiliensis* Steindachner," also from Rio de Janeiro, Brazil; they were found to be identical with it.

S. brasiliensis is close to *anchovia* according to a limited number of rather indifferently preserved specimens, from Cuba and Jamaica. However, specimens from Port-of-Spain, Trinidad, and from Venezuela are quite distinct from those of our Atlantic coast, the most outstanding difference being the greater number of gill rakers in *brasiliensis*; other differences include the position of the dorsal and pelvic fins, the size of the eye, and the length of maxillary and pectoral fin.

The numerous specimens from Rio de Janeiro, Brazil, examined and measured in part, differ somewhat from those taken at Port-of-Spain, Trinidad, which serve chiefly as the basis for this description. In fact, the former are less distantly removed from specimens of *anchovia* from the eastern United States than from those of Trinidad, as the eye runs a little smaller (5.75–7.25 $^0/_0$ of SL), the maxillary is rather shorter (9.5–11 $^0/_0$ of SL), the pectoral is a little shorter (16–18 $^0/_0$ of SL), and the gill rakers are somewhat less numerous (108–117 in specimens 97–109 mm SL). Therefore, a subspecific difference is suggested. Indeed, it seems highly probable that further study will show some intergradation among all species recognized in these pages.

S. brasiliensis, like *S. anchovia*, apparently was incorrectly synonomized with *S. aurita* of Europe and elsewhere by Regan (p. 405). According to data based on specimens from Messina, Sicily, its type locality, *aurita* grows larger than *brasiliensis* and has fewer gill rakers in examples of equal size. These species may therefore be regarded as valid unless further evidence shows this opinion to be incorrect.

Commercial Importance. This sardine is of at least some commercial importance at Port-of-Spain, Trinidad, where Waldo L. Schmitt of the U. S. National Museum obtained from the market (April 18, 1939) the fine series of specimens used in preparing the foregoing description. It is abundant and occurs also in large numbers in the market at Rio de Janeiro, Brazil, but southward in the state of São Paulo it is less numerous (*25*: 188).[48]

Range. The west coast of Florida, the West Indies, and Venezuela to southern Brazil. Not reported for México to Colombia.

Synonyms and References:

Clupea brasiliensis Steindachner, S. B. Akad. Wiss. Wien, *80*, 1879; Ichthyol. Beitr., 8: 64 (orig. descr.;[49] type local. Rio de Janeiro, Brazil).

Sardinella aurita Regan (in part), Ann. Mag. nat. Hist., (8) *19*, 1917: 378 (synon., in part *anchovia*; descr. in part; range); Campos, Arqu. Zool. estad. São Paulo (1941), *3* (7), 1942: 188, fig. 2 (synon., descr., abund. in market, range, specimens coll. in Brazil); Oliveira (not of Cuvier and Valenciennes), Min. Agr. Dep. Nac. Pro. Anim., Div. Caça e Pesca, 1942: 22 (ref., range).

Clupanodon pseudohispanicus Beebe and Tee-Van (in part *anchovia*), Zoologica, N.Y., *10* (1), 1928: 39 (refs., field char., discus.).

Sardinella brasiliensis Longley *in* Longley and Hildebrand, Publ. Carneg. Instn. Wash., 535, 1941: 7 (cf. *anchovia* and *aurita*).

Doubtful References:

Clupanodon pseudohispanicus Evermann and Kendall, Rep. U. S. Comm. Fish. (1899), 1900: 55 (Pensacola and Snapper Banks, Florida).

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[48] The Brazilian Sardinha, or Sardinha Verdadeira (true sardine), is the most important market fish in the area between Victoria, Espirito Santo, and Santos, São Paulo. It is not taken commonly north of this area, and it is to be questioned that this fish is identical with the populations farther to the north.—G.S.M.

[49] Fowler has shown that *Clupea brasiliensis* Steindachner 1879 is a primary homonym of *Clupea brasiliensis* Schneider 1801 (equals *Albula vulpes*). Fowler uses the specific name *allecia* (of Rafinesque), but the latter applies to European fish, which Fowler, following Regan, would apparently unite with the American form. If the American form is distinct it would appear to be nameless, unless changes in the International Rules of Zoological Nomenclature, now said to be imminent, would restore the availability of Steindachner's name. Until this genus is adequately revised for the entire Atlantic and the relationships of the American and European populations are worked out, it would seem premature to disturb the nomenclature.—G. S. M.

Sardinella anchovia Schreiner and Miranda-Ribeiro, Arch. Mus. nac., Rio de J., 12, 1903: 91 (Rio de Janeiro, range, names); Metzelaar (probably not of Cuvier and Valenciennes), Rapp. Vissch. Curaçao, ed. by Boeke, 1, W. Indian Fishes, 1919: 10, fig. 2 (Dutch West Indies: fig. seems based on *brasiliensis* as herein understood).

Sardinella aurita von Ihering (not of Cuvier and Valenciennes), Rev. Industr. Anim., 1 (3), 1930: 228 (synon., fin rays, scales, ventral scutes, Brazil).

Genus *Rhinosardinia* Eigenmann 1912

Rhinosardinia Eigenmann, Mem. Carneg. Mus., *5*, 1912: 445; type species by original designation, *Rhinosardinia serrata* Eigenmann. Myers, Copeia, 1929: 1; *Heringia* preoccupied in *Diptera*.

Generic Synonym:

Heringia Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 207; type species by original designation, *Clupea amazonica* Steindachner; name preoccupied in Diptera.

Characters. BODY moderately elongate, strongly compressed; ventral outline more strongly convex than dorsal outline. BONY SCUTES on chest and abdomen well developed, the posterior one ending in a rather long sharp spine. SCALES adherent, each with a prominent vertical groove having more or less horizontal laterals (not verified in *bahiensis*). MOUTH strongly oblique. MANDIBLE projecting. MAXILLARY broadly rounded posteriorly, with a strong sharp backward projecting spine near its anterior end (Fig. 103); maxillary-premaxillary margin continuous, composed of a soft membranous section; entire margin toothless. TEETH absent on vomer, but present on mandible (at least in *serrata* and *bahiensis*), palatines, pterygoids, and tongue. GILL RAKERS rather numerous (about 30–40 on lower limb of first arch in *serrata*), close-set. DORSAL fin about over middle of body, with approximately 14–17 rays. ANAL fin scarcely longer than dorsal and placed well behind it, with about 15–18 rays. PELVIC well developed, with 8 rays. PECTORAL rather small, more or less equal to head in length.

Remarks. This genus differs from all others of this family in the presence of a small sharp spine on the anterior part of the maxillary, close behind the premaxillary. It differs further from related genera in the small anal fin, which is situated well behind the dorsal fin.

Range. This genus of small herrings is confined to northeastern and northern South America, from Rio de Janeiro to Venezuela, in fresh, brackish, and salt water.

Key to Species

1a. Sides with a prominent silvery lateral band, about as wide as eye; origin of dorsal about over insertion of pelvic fin and nearly an eye's diameter nearer to tip of snout than to base of caudal; teeth present on mandible, maxillary, and premaxillary; dorsal with 17 rays; anal with 18; scales 44. *bahiensis* (Steindachner) 1879.
Coast of Brazil from Bahia (Baía) to Rio de Janeiro.

1 b. Sides without silvery band; origin of dorsal definitely behind insertion of pelvic fin and about equidistant between margin of snout and base of caudal; teeth missing on maxillary and premaxillary; dorsal with 14 or 15 rays; anal with 15–17 rays; scales 35–38.

2 a. Greatest depth of body 3.5–4.0 in SL (75- and 40-mm specimens, respectively); depth of caudal peduncle close to half of greatest depth of body; head 4.0 in SL; snout 4.0 in head; base of dorsal fin about as long as its longest rays. *amazonica* (Steindachner) 1879, below.

2 b. Greatest depth of body 3.1–3.4 (60–68-mm specimens) in SL; depth of caudal peduncle definitely less than half of greatest depth of body; head 4.25–5.1 in SL; snout 4.6–5.5 in head; base of dorsal fin notably shorter than its longest rays. *serrata* Eigenmann 1912, p. 413.

Rhinosardinia amazonica (Steindachner) 1879

Study Material. None.

Distinctive Characters. This species is closely related to *serrata*. However, *amazonica* differs from *serrata*, according to the original description, in the somewhat more slender body, slightly larger head, longer snout, the proportionately deeper caudal peduncle, in the absence of teeth on the mandible, and in the somewhat different proportion of the longest dorsal rays with respect to the head length and dorsal base.

Description. Proportional dimensions in per cent of standard length, and counts, modified after the original description by Steindachner (see Synonyms and References).

Body: depth 27.5 in 75-mm examples, about 25 in those 40 mm long.
Head: length 25.
Scales: 37.
Ventral scutes: 27.
Fin rays: dorsal 15; anal 16.

BODY strongly compressed, its ventral outline notably more strongly convex than dorsal outline, its greatest depth 3.5 in SL in large examples, 4.0 in smaller ones. CAUDAL PEDUNCLE deep in comparison with depth of body, close to half of greatest depth.

SCALES adherent; about 37 in a horizontal row between margin of opercle and base of caudal; a vertical groove dividing the free (exposed) part of scale from the covered part, 2 or 3 sharp grooves on the former. VENTRAL SCUTES on chest and abdomen, 15 in front of pelvic fins and 12 behind them.

HEAD 4.0 in SL. SNOUT 4.0 in head. EYE 3.0. MOUTH small. MAXILLARY reaching little beyond anterior margin of eye. MANDIBLE projecting little. TEETH absent on premaxillary, mandible, and vomer.

DORSAL fin with base about as long as longest rays, its origin a little behind vertical at insertion of pelvic, and equidistant between end of head (snout) and base of caudal.

CAUDAL about 1.5 times length of head, with slender pointed lobes covered with scales anteriorly.

Color. Body silvery; head yellowish white.

Size. The largest example reported was 75 mm long.

Development. Small specimens (40 mm) are more slender than larger ones (75 mm), according to the original description, and the ventral outline is strikingly less convex in the smaller ones. However, the proportionate depth of the caudal peduncle and the greatest depth of the body are about the same in both small and large specimens.

Range. Known only from Pará, Brazil.

Synonyms and References:

Clupea amazonica Steindachner, S. B. Akad. Wiss. Wien, *80*, 1879; Ichthyol. Beitr., *8*: 65 (orig. descr., type local. "Amazon R. at Pará"); von Ihering, Dic. Anam. Brasil, 1940: 716 (habitat).

Rhinosardinia amazonica Myers (in part not of Steindachner), Copeia, 1929: 1 (*R. serrata* thought to be a synon., following Regan, which seems to be incorrect).

Sardinella (*Rhinosardinia*) *amazonica* von Ihering, Rev. Indust. Anim., 1 (3), 1930: 229 (synon., diagn., relation.).

Negative Reference:

Heringia amazonica Regan (not of Steindachner), Ann. Mag. nat. Hist., (8) *19*, 1917: 394 (descr. based on cotypes of *R. serrata*; synon. apparently incorrect).

Rhinosardinia serrata Eigenmann 1912

Figures 102, 103

Study Material. Five cotypes, 60–68 mm TL, 46–49 mm SL, from Morawhanna, British Guiana, USNM 66284.

Distinctive Characters. See *Relationship*.

Description. Proportional dimensions in per cent of standard length, and counts, based on the five cotypes, 46–49 mm SL.

Body: depth 29.5–32.
Caudal peduncle: depth 1.55–1.95.
Head: length 19.5–23.5; depth 20.5–21.5.
Snout: length 4.1–4.55.
Eye: diameter 6.2–6.75.
Interorbital: width 4.25–4.8.
Maxillary: length 9.1–10.
Mandible: length 8.4–9.1.
Anal fin: length of base 12.7–14.3.
Pelvic fin: length 15.5–17.
Pectoral fin: length 19.2–20.5.
Distance from snout to origin of: dorsal 47–51.

Scales: 35–38.
Ventral scutes: 27–29.
Fin rays: dorsal 14 or 15; anal 15–17; pectoral 11 or 12.
Vertebrae: 29 (105: 394).

BODY rather deep but not excessively compressed, its greatest thickness about a fourth of its depth, its greatest depth 3.1–3.4 in SL; dorsal outline gently convex anteriorly, the ventral outline somewhat more strongly convex. CAUDAL PEDUNCLE scarcely as long as deep, its depth definitely less than half of greatest depth of body, 1.55–1.95 in head.

SCALES closely adherent, thin, almost circular, with even margin and with a prominent, nearly complete vertical groove provided with 1–3 horizontal branches on each side; scales extending well out on caudal fin. VENTRAL SCUTES well developed, especially the posterior ones, each with a prominent spine, 16 in advance of pelvic fins and 11–13 behind them.

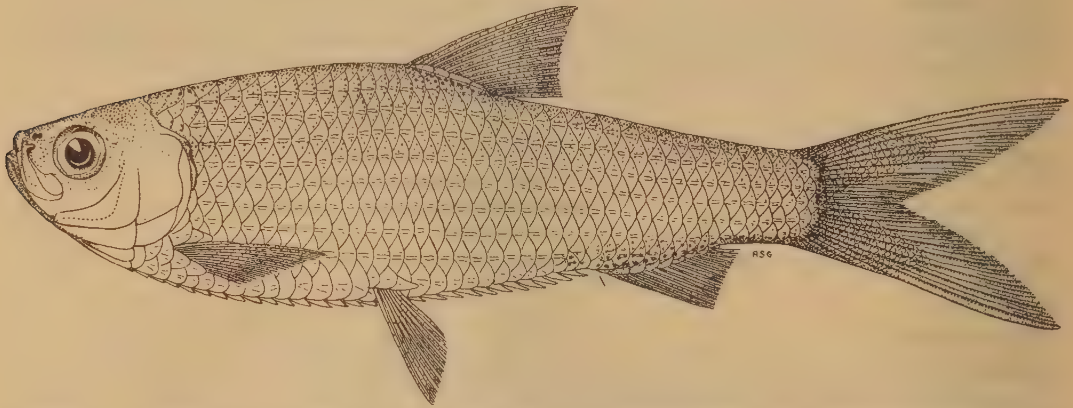

FIGURE 102. *Rhinosardinia serrata*, 63 mm TL, 47 mm SL, Morawhanna, British Guiana, cotype, USNM 66284. Drawn by Ann S. Green.

HEAD rather short and deep, its length 4.25–5.1 in SL, its depth at vertical from crossgroove at occiput 4.65–4.9. SNOUT definitely shorter than eye, 4.6–5.5 in head. EYE 3.0–3.8. INTERORBITAL moderately narrow, 4.1–5.25 in head. CHEEK longer than deep. MOUTH strongly oblique. MAXILLARY broadly rounded posteriorly, reaching nearly or quite below anterior margin of pupil, 2.1–2.5 in head. MANDIBLE projecting moderately, its margin within mouth rising strongly, forming a broadly rounded obtuse angle, 2.15–2.6 in head. GILL RAKERS slender, close-set, very difficult to count, approximately half as long as eye, about 35–40 on lower limb. TEETH all minute, present on mandible anteriorly and on palatines, pterygoids, and tongue, but absent on maxillary, premaxillary, and vomer.

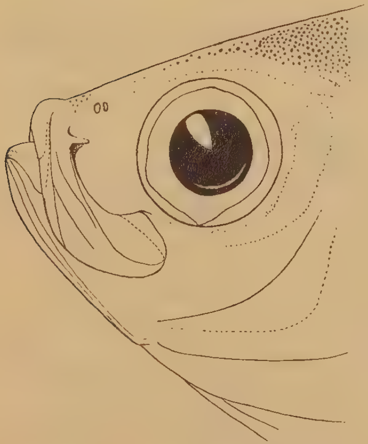

FIGURE 103. *Rhinosardinia serrata* head showng spine near end of maxillary, from specimen in Fig. 102. Drawn by Ann S. Green.

DORSAL fin well developed, rather high anteriorly, its margin concave, its longest rays exceeding the length of base, about as long as head, reaching far beyond tip of last ray if deflexed, its origin slightly nearer to margin of snout than to base of caudal, its distance from margin of snout 1.95–2.1 in SL, its base nearly as long as that of the anal; a narrow sheath of scales on anterior part of base. CAUDAL fin long, rather deeply forked, the upper lobe exceeding greatest depth of body by more than diameter of eye. ANAL fin small, its origin about half of length of head behind base of dorsal and a little nearer to base of caudal than to insertion of pelvic, its base notably shorter than head, 6.9–7.8 in SL; a narrow sheath of scales at base. PELVIC fin long, pointed, inserted about half of eye's diameter in advance of dorsal fin and about equidistant between base of pectoral and vent, 1.2–1.5 in head. PECTORAL failing to reach base of pelvic by diameter of eye, scarcely as long as head, 4.9–5.0 in SL.

Color. Brownish in alcohol, with metallic reflections. Sides of head silvery. Back, upper surface of head, snout, and mandible with dusky dots; dusky dots also on the fins, exclusive of pelvics.

Size. The largest specimens reported to date are only 85 mm (3.4 in.) TL.

Relationship. This species was synonymized with *R. amazonica* by Regan in his revision of this and related genera (*106*: 394). A careful rereading of the original description of *amazonica*, with syntypes of *serrata* in hand, reveals some differences that seem too important to dismiss. Accordingly, the species herein are recognized as distinct. For a definite determination of the relationship of the two species, a more accurate description of specimens from the type locality of *amazonica* is needed.

Range. Known from Venezuela and from Dutch and British Guiana.

Synonyms and References:

Heringia amazonica Fowler (probably not of Steindachner, but *serrata* Eigenmann), Proc. Acad. nat. Sci. Philad., *63*, 1911: 207 (14 specimens from "Surinam"; made type of a new genus, *Heringia*; preoccupied in Diptera); Regan (not of Steindachner), Ann. Mag. nat. Hist., (8) *19*, 1917: 394 (*Rhinosardinia serrata* Eigenmann apparently incorrectly synon.; descr. based on cotypes of *R. serrata*).

Rhinosardinia serrata Eigenmann, Mem. Carneg. Mus., *5*, 1912: 445, text fig. 39, pl. 62, figs. 3 and 4 (orig. descr., type local. Morawhanna and Mora Passage, British Guiana; type CM 2443).

Rhinosardinia amazonica Myers (in part not of Steindachner), Copeia, 1929: 1 (*R. serrata* thought to be synon., following Regan, which seems to be incorrect); Fowler (probably not of Steindachner, but *serrata* Eigenmann), Proc. Acad. nat. Sci. Philad., *83*, 1931: 406 (name and locals. only; Caño Guanoco and Punta Tigre at mouth of San Juan R., Venezuela).

Genus *Ilisha* Gray 1846

Ilisha Gray *in* Richardson, Ichthyol. Seas of China, Japan, Rep. Brit. Ass. Adv. Sci. (1845), 1846: 306; type species by monotypy, *Ilisha abnormalis* Gray equals *Alosa elongata* Bennett; Myers, Copeia, 1950: 63; notes on identity with *Neosteus* and *Pseudochirocentrodon*.

Generic Synonyms:

Platygaster Swainson, Nat. Hist. Fish. Amphib. Rept., *2*, 1839: 294; type species *Clupea africana* Bloch, first designated by Jordan, Genera Fishes, 1919: 203; name preoccupied in bees.

Pellona Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 300; type species *Pellona orbignyana* Cuvier and Valenciennes, first designated by Gill, Proc. Acad. nat. Sci. Philad., 1861: 37; but *P. orbignyana* equals *Pristigaster flavipinnis* Valenciennes (*in* d'Orbigny), Voyage Amer. Merid., Poiss., 5 (2), 1847: 8; Atlas, d'Orbigny, 1839: pl. 10, fig. 2.

Zunasia Jordan and Metz, Mem. Carneg. Mus., *6*, 1913: 7; type species by monotypy, *Pristigaster chinensis* Basilewsky equals *Alosa elongata* Bennett.

Pseudochirocentrodon Miranda-Ribeiro, Publ. Comm. Linhas Telegr. Estrat. Matto Grosso Amazonas, 58, 1923 ("1920"): 8; type species by monotypy, *P. amazonicum* Miranda-Ribeiro.

Neosteus Norman, Ann. Mag. nat. Hist., (9) *11*, 17, 1923: type species *Pellona ditchela* Valenciennes by subsequent designation of Norman, Zool. Rec., Pisces, for 1923: 25.

Characters. BODY elongate, rather strongly compressed, its ventral outline more strongly convex than dorsal outline. BONY SCUTES strong, about 25–37 along sharp edge on chest and abdomen. SCALES small to rather large, often missing on preserved specimens, generally with several irregular vertical grooves. SNOUT with or without a definite median notch. MOUTH moderate, strongly oblique. MANDIBLE projecting strongly. MAXILLARY generally reaching under anterior half of eye, with a bone or ligament between it and premaxillary. TEETH all small, present in a single series on anterior part of mandible, on premaxillaries, maxillaries, and usually in bands on palatines, pterygoids, and tongue, but none on vomer. GILL RAKERS strong, serrate, about 12–25 on lower limb of first arch (in American species). DORSAL fin with about 15–20 rays (in American species). ANAL fin long, its origin under posterior rays of dorsal or just behind that fin, with about 36–52 rays (in American species). PELVIC fin small (occasionally absent in one species), with 6 or 7 rays (in American species).

Remarks. This genus is characterized by the elongated, compressed body with a strongly convex ventral outline, by the very long anal fin, and by the small pelvic fin, inserted in advance of the dorsal fin and consisting of only 6 or 7 rays. Furthermore, the premaxillary and maxillary are not adjoined, a soft ligament (in *Ilisha*) or a bone (in *Neosteus*) being present between them.[50]

Range. Tropical parts of the Atlantic, Indian, and Pacific oceans. Fresh waters of the Amazon Basin. One species, *I. narragansetae*, reported from Rhode Island.

Key to Species of the Western Atlantic and Tributary Rivers

1a. Ventral scutes 20–25 before and 10–14 behind pelvic fins, total number 32–37.
  2a. Gill rakers only 12 or 13 on lower limb; scales 72–75 in a lateral series; depth of body less than a third (27.5–30 %) of SL.
    altamazonica Cope 1872, p. 417.
  2b. Gill rakers 23–31 on lower limb; scales fewer than 70 in a lateral series; depth of body about equal to a third (30–37 %) of SL.
    3a. Dorsal fin with 19 or 20 rays; gill rakers on lower limb 23–26; axillary process of pectoral reaching middle of first ray.
      castelnaeana (Cuvier and Valenciennes) 1847, p. 419.

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[50] See Myers (97: 63) for discussion.

3b. Dorsal fin with 17 or 18 rays; gill rakers on lower limb 30 or 31; axillary process of pectoral not reaching middle of fin.
flavipinnis Valenciennes 1839.
Buenos Aires, Argentina.

1b. Ventral scutes 19–25 before and only 6 or 7 behind pelvic fins, total number 25–32.
  4a. Depth of body less than a third (30 %) of SL; scales about 60 in a lateral series; gill rakers 19 on lower limb; anal with 47–52 rays.
  amazonica (Miranda-Ribeiro) 1923, p. 421.
  4b. Depth of body about equal to or greater than a third (33–40 %) of SL; scales 33–45 in a lateral series; gill rakers 22–25 on lower limb.
    5a. Depth of body greater than a third (37–40 %) of SL; ventral scutes 19–21 before and 6 behind pelvic fins; pectoral with 13–15 rays; anal with 36–42 rays. *harroweri* Fowler 1917, p. 423.
    5b. Depth of body about equal to a third (33 %) of SL; ventral scutes 25 before and 7 behind pelvic fins; pectoral with 16 rays; anal with 45 rays.
    narragansetae Fowler 1911, p. 426.

Ilisha altamazonica (Cope) 1872

Apapa

Figure 104

Study Material. Three specimens, 280, 305, and 360 mm TL, 220, 234, and 275 mm SL, from "the Amazon River region, Pará to Manáos," Brazil, USNM 52548.

Distinctive Characters. This species is characterized by the slender body and small scales. It differs especially from related species in the very few gill rakers on the lower limb of the first arch.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 220–275 mm SL.

Body: depth 27.5–30.
Caudal peduncle: depth 9.4–9.5.
Head: length 25.5–27; depth 21.5–23.5.
Snout: length 5.15–5.5
Eye: diameter 6.2–6.8.
Interorbital: width 12–13.5.
Maxillary: length 12.8–13.5.
Mandible: length 14–15.
Anal fin: length of base 29–31.
Pelvic fin: length 7.5–8.1.
Pectoral fin: length 20.5–22.7.
Distance from snout to origin of: dorsal 50–52.

Scales: 72–75.
Ventral scutes: 32 or 33.
Fin rays: dorsal 18; anal 37–40; pectoral 16 or 17.

Body quite slender, rather strongly compressed, its greatest thickness about 2.5 times in its depth, its greatest depth 3.3–4.65 in SL; the dorsal outline gently convex, the ventral outline much more strongly convex. Caudal peduncle rather strong, its depth 2.7–2.8 in head.

Scales adherent; those on middle of side below anterior rays of dorsal definitely deeper than long, without vertical grooves, closely imbricated; the exposed part rather more than two times deeper than long: the membranous margin only slightly irregular. Ventral scutes moderately developed, 22 or 23 in advance of pelvic fins and 10 or 11 behind them.

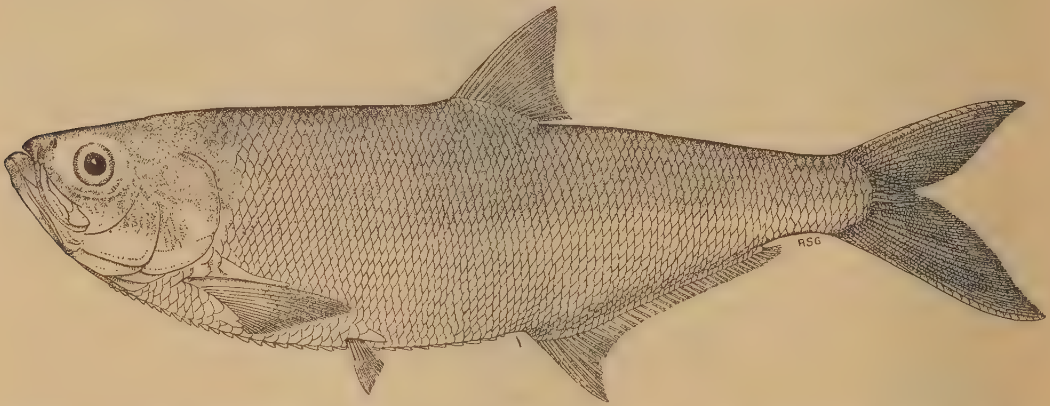

Figure 104. *Ilisha altamazonica*, 360 mm TL, 275 mm SL, Amazon River somewhere between Pará and Manáos, Brazil, USNM 52548. Drawn by Ann S. Green.

Head 3.7–3.9 in SL, its depth at vertical from slight crossgroove at occiput 4.25–4.65. Snout only a little shorter than eye, with a prominent median notch, 2.0–2.05 in head. Eye with much adipose tissue, 3.9–4.3. Interorbital 2.0–2.15 in head. Cheek deeper than long. Maxillary rather narrowly rounded posteriorly, reaching below middle of eye, 2.0–2.05 in head; a narrow bone with teeth between premaxillary and maxillary. Mandible projecting strongly, its tip scarcely below dorsal outline of head, its margin within mouth rising gently, 1.8–1.85 in head. Gill rakers at angle of first arch about 75 % of length of eye, only 12 or 13 on lower limb. Teeth small, in a single row, on anterior part of mandible and on premaxillaries; minute teeth on margin of maxillary, and still smaller teeth on the bone between premaxillary and maxillary; bands of minute granular teeth on palatines, pterygoids, and tongue.

Dorsal fin rather high anteriorly, its longest rays reaching far beyond the tip of last ray if deflexed, its origin equidistant between margin of snout and base of caudal, or a little nearer to snout, its distance from margin of snout 1.9–2.0 in SL; a sheath composed of a single row of scales at its base. Caudal fin well forked, the lower lobe much the longer; small scales extending onto the fin, covering most of it. Anal fin long, with a definite lobe anteriorly, its origin immediately behind a vertical from last dorsal ray, only a little nearer to margin of opercle than to base of caudal, its base 3.2–3.4

in SL; a sheath composed for the most part of two rows of scales at its base. PELVIC fin small, inserted fully an eye's diameter in advance of vertical from origin of dorsal and a little nearer to base of pectoral than to origin of anal, 3.15–3.45 in head; free axillary process about 66 % of the length of fin. PECTORAL fin reaching well beyond base of pelvic, its length 4.4–4.9 in SL, 1.15–1.3 in head; a free axillary process present along about 66 % of length of fin.

Color. Old preserved specimens grayish brown above, silvery below, with indefinite alternating light and dark streaks along the rows of scales. A slight shoulder spot present. Interorbital, upper surface of snout, and tip of mandible dark brown. Dorsal, caudal, and pectoral fins largely dusky, the lower lobe of caudal with a dark area on its middle rays, this area narrow anteriorly but spreading posteriorly.

Range. Originally described from the Ambyiacu River, a tributary emptying into the Amazon near Pebas, Peru; also reported from Iquitos, Peru, and the Tocantins River, Brazil. The three specimens now at hand are from the lower Amazon.

Synonyms and References:

Pellona altamazonica Cope, Proc. Acad. nat. Sci. Philad., 1872: 265 (orig. descr.; type local. Ambyiacu R., trib. of upper Amazon).

Ilisha altamazonica Eigenmann, Rep. Princeton Exped. Patagonia, 1896–1899, *3* (4), 1910: 452 (ref., range); Eigenmann and Allen, Fishes West. S. Amer., 1942: 333 (refs., range); Myers, Copeia, 1950: 64 (synon.).

Neosteus altamazonica Norman, Ann. Mag. nat. Hist., (9) *11*, 1923: 19 (ref., descr.).

Ilisha (*Neosteus*) *altamazonica* von Ihering, Rev. Indust. Anim., 1 (3), 1930: 230 (fin rays; note "Amazonas, rio Tocantins").

Ilisha desuratus Nakashima, Bol. Mus. Hist. Nat., "Javier Prado," 5 (16), 1941: 77, fig. (orig. descr.; type local., environs of Iquitos, Peruvian Amazon).

Negative Reference:

Ilisha altamazonica de Menezes (not of Cope). Publ. Serv. Piscic., Dep. Nac., Ceará, Brazil, 113, 1946: 1 (notes on common name; local. of coll., ident., etc. Later publication [113A, 1947: 1] refers this to synon. of *I. castelnaeana*).

Ilisha castelnaeana (Cuvier and Valenciennes) 1847

Cagona, Apapa, Sardinha Grande, Pirapema, Gros Hareng

Study Material. None.

Distinctive Characters. See *Relationship.*

Description. Proportional dimensions in per cent of standard length, and counts, after Norman (99: 19), "three specimens 280–390 mm in length," presumably TL.

Body: depth 33.3–37.
Head: length 26.5–27.5.
Anal fin: length of base 28–29.
Scales: 63–66.
Ventral scutes: 34–37.
Fin rays: dorsal 19 or 20; anal 40 or 41.

Body with greatest depth 3.25–3.33 in SL; the ventral outline more strongly convex than dorsal outline. Scales relatively small. Ventral scutes 21–23 in advance of pelvics and 13 or 14 behind them. Snout a little shorter than eye. Eye 3.8–4.0 in head. Maxillary extending to or a little behind middle of eye. Mandible projecting strongly. Gill rakers 23–26 on lower limb of first arch. Dorsal origin nearer to margin of snout than to base of caudal. Anal with origin behind dorsal base, its base 3.5–3.6 in SL. Pelvic longer than eye, inserted much nearer to base of pectoral than to origin of anal. Pectoral with axillary process reaching to or beyond middle of first ray of fin.

Color. According to the original account, greenish above, silvery ventrally. Lower lobe of caudal with a large dark spot; other fins yellowish.

Size. See *Description.*

Relationship. This species seems to be closely related to *I. flavipinnis*, a species apparently reported only from Buenos Aires, Argentina, with which *castelnaeana* has sometimes been considered identical. According to Norman, the latest revisor of this and related genera, *flavipinnis* has more gill rakers on the lower limb of the first arch (30 or 31) and an axillary process of the pectoral fin that is shorter, not reaching the middle of the first ray (99: 17). These differences seem to be substantiated by two specimens (USNM 77357) about 220 and 230 mm TL (caudal damaged), 173 and 187 mm SL, from Buenos Aires. Furthermore, the dorsal and anal of *flavipinnis* seem to have fewer rays (D. 17 and 18; A. 38 and 39) and a shorter anal fin base (3.45 and 3.55 in SL). In color the specimens of *flavipinnis* differ from *castelnaeana*, as described, in the absence of a dark spot on the lower lobe of the caudal.

Range. "Coast of Surinam and Brazil; Upper Amazons" (Norman).

Synonyms and References:

Pellona castelnaeana Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 306 (orig. descr.; type local., around mouth of Amazon R.); Fowler, Arqu. Zool. estad. São Paulo, 3 (6), 1941: 134 (refs.).

Pellona flavipinnis Günther (not of Valenciennes), Cat. Fish. Brit. Mus., *7*, 1868: 454 (descr. based on specimens from Surinam, where species does not occur); Boulenger (not of Valenciennes), Ann. Mag. nat. Hist., (6) *20*, 1897: 298 (Marajó I., Brazil); Goeldi (not of Valenciennes), Bol. Mus. Paraense Hist. Nat., *2* (3), 1898: 486 (refs., names); Puyo (not of Valenciennes), Bull. Soc. Hist. nat. Toulouse, *70*, 1936: 166 (refs., descr., habits, habitat, commerc. import.).

Ilisha flavipinnis Jordan and Evermann (not of Valenciennes), Bull. U. S. nat. Mus., 47 (1), 1896: 435 (descr. after Günther, 1868); Eigenmann (in part not of Valenciennes), Rep. Princeton Exped. Patagonia, 1896–1899, *3* (4), 1910: 452 (*I. castelnaeana* incorrectly synon., range, includ. both species); Eigenmann (not of Valenciennes), Mem. Carneg. Mus., *5*, 1912: 446 (descr., Georgetown, British Guiana, where species does not occur); Starks (not of Valenciennes), Stanf. Univ. Publ., Univ. Ser., 1913: 8 (Pará, Brazil, where species apparently does not occur).

Neosteus castelnaeana Norman, Ann. Mag. nat. Hist., (9) *11*, 1923: 19 (synon., descr., range).

Ilishe (*Neosteus*) *castelnaeana* von Ihering, Rev. Industr. Anim., 1 (3), 1930: 230 (refs., fin rays; "Amazonias e Guyana; entra no rias").

Ilisha altamazonica de Menezes (not of Cope), Publ. Serv. Piscic. Dep. Nac., Ceará, Brazil, 113, 1946: 1 (notes on common name; local. of coll., ident., etc.).

Ilisha castelnaeana de Menezes, Publ. Serv. Piscic. Dep. Nac., Ceará, Brazil, 113A, 1947: 1 (*I. altamazonica* of de Menezes, 1946, to synon. of this species).

Ilisha amazonica (Miranda-Ribeiro) 1923

Apapa, Sardina, Asuna Nãhui

Figure 105

Study Material. Type of *I. apapae*, about 200 mm TL (caudal damaged), 160 mm SL; exact place of capture unknown, being registered merely as having been collected in "the Amazon River region, Pará to Manáos," Brazil; USNM 52550.

Distinctive Characters. This species differs from the other local species in having a ligament between the premaxillary and maxillary; the others have a narrow bone bearing fine teeth along the margin. Its body is slender as in *altamazonica*, but its scales are apparently somewhat larger, its dorsal rays fewer, and its anal rays more numerous. It has more gill rakers than *altamazonica* but fewer than the other species herein described. It is nearest to *furthii* of the Pacific coast of tropical America, which also has a ligament between the premaxillary and maxillary; but it differs from that species in having fewer ventral scutes (34–37 in *furthii*), and in the position of the pelvic fin—inserted notably nearer to the origin of anal than to the base of pectoral in *amazonica* but equidistant between these points in *furthii*; also they differ in several other respects.

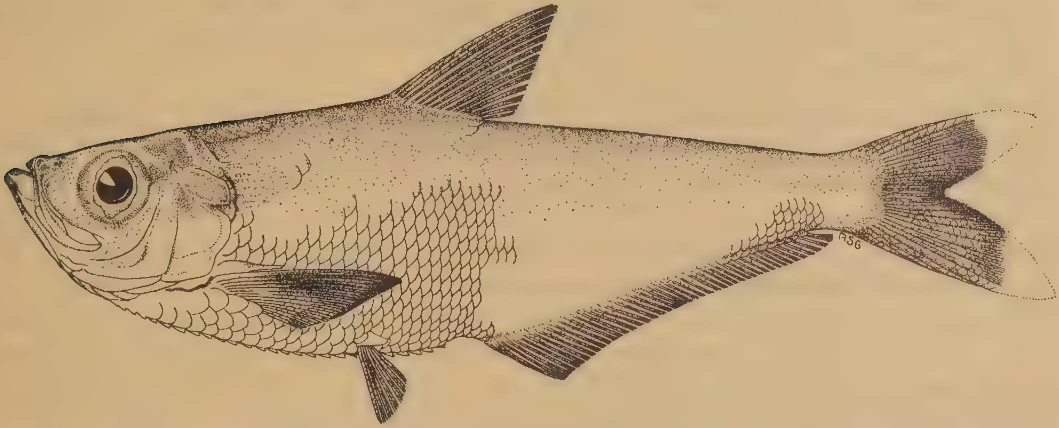

FIGURE 105. *Ilisha amazonica*, about 200 mm TL (caudal damaged), 160 mm SL, Amazon River, Brazil, type of *I. apapae*, USNM 52550. Drawn by Ann S. Green.

Description. Proportional dimensions in per cent of standard length, and counts, based on *Study Material*, specimen 160 mm SL.

Body: depth 30.5.
Caudal peduncle: depth 8.75.
Head: length 25; depth 23.5.
Snout: length 5.6.
Eye: diameter 6.8.
Interorbital: width 2.5.
Maxillary: length 13.2.
Mandible: length 14.5.

Anal fin: length of base 42.
Pelvic fin: length 10.5.
Pectoral fin: length 23.
Distance from snout to origin of: dorsal 44.
Scales: *ca.* 60, mostly missing.[51]
Fin rays: dorsal 15; anal 47;[51] pectoral 14.
Ventral scutes: 26.[51]

Body strongly compressed, its greatest thickness scarcely a third of its depth, its greatest depth 3.25 in SL; the dorsal outline anterior to dorsal nearly straight, the ventral outline strongly convex. Caudal peduncle 2.85 in head.

Scales mostly lost; the scales on middle of side below base of dorsal scarcely deeper than long, with 4 or 5 vertical striae, only the posterior one complete; not very closely imbricated; the exposed part of scale notably greater than half of its depth, the margin nearly smooth. Ventral scutes well developed, 20 in advance of pelvic fins and 6 behind them.

Head 4.0 in SL, its depth at vertical from slight crossgroove at occiput 4.2. Snout definitely shorter than eye, without a definite median notch, 4.45 in head. Eye 2.9. Interorbital 10 in head. Cheek fully as deep as long. Maxillary narrowly rounded posteriorly, reaching below anterior margin of pupil, 1.85 in head. A soft ligament between premaxillary and maxillary. Mandible projecting strongly, its tip scarcely below dorsal outline of head, its margin within mouth rising rather strongly, forming an obtuse angle, 1.75 in head. Gill rakers at angle of first arch scarcely half of length of eye, 19 on lower limb of first arch. Teeth small; a few in a single row on anterior part of mandible, a series on premaxillary and on margin of maxillary, and bands of granular teeth on palatines, pterygoids, and tongue.

Dorsal fin high anteriorly, its longest rays reaching far beyond tip of last ray if deflexed, only a little shorter than the head, its origin nearer to margin of snout than to base of caudal by a distance equal to length of snout and eye, its distance from margin of snout 2.3 in SL. Caudal forked (damaged), the lower lobe evidently the larger; small scales covering most of fin. Anal fin long, scarcely elevated anteriorly, its anterior rays not forming a definite lobe, its origin under last ray of dorsal and equidistant between posterior margin of eye and base of caudal, its base 2.4 in SL; a scaly sheath present. Pelvic fin long (for an *Ilisha*), inserted rather less than an eye's diameter in advance of vertical from origin of dorsal and nearer to origin of anal than to base of pectoral, 2.3 in head; a short broad axillary process present. Pectoral fin reaching beyond base of pelvic by a distance fully equal to diameter of pupil, 4.3 in SL, 1.05 in head; the short free axillary process only a little more than a third of the length of fin.

Color. Old preserved specimen grayish above, yellowish to silvery below. Upper surface of snout and tip of mandible dark brown; a brownish area behind eye. All fins with dusky punctulations, these few and scattered on pelvic, most numerous on dorsal, caudal, and upper half of pectoral.

Range. Known only from the Amazon.

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[51] If Myers (97: 63–64) is correct in referring *I. apapae* and *I. iquitensis* to the synonymy of this species, then the anal rays vary from 47 (types of *amazonica*) to 52 (type of *iquitensis*), the scales from 57 to about 60, and the total number of ventral scutes 25 or 26.—G. S. M.

Synonyms and References:

Pseudochirocentrodon amazonicum Miranda-Ribeiro, Publ. Comm. Linhas Telegr. Estrat. Amazonas, 58, 1923 ("1920"): 8 (orig. descr., type local. Manáos, Estado de Amazonas, Brazil).

Ilisha iquitensis Nakashima, Bol. Mus. Hist. Nat. "Javier Prado," 5 (16), 1941: 66, fig. (orig. descr.; type local. environs of Iquitos, Peruvian Amazon).

Ilisha apapae Hildebrand, Smithson. misc. Coll., *110* (9), 1948: 3, fig. 2 (orig. descr.; type local. Rio Amazonas somewhere between Pará and Manáos, Brazil; type USNM 52550).

Ilisha amazonica Myers, Copeia, 1950: 63 (synon., types of *P. amazonicum* and *I. apapae*).

Ilisha harroweri Fowler 1917

Caille (Trinidad)

Figure 106

Study Material. Twenty-two specimens, 45–155 mm TL, 34–122 mm SL, from Atlantic coast of Panama (20 specimens) and Port-of-Spain, Trinidad (2). One from Barro Santos and another from Porto Inhuana, southern Brazil, were compared and probably belong to this species.

Distinctive Characters. See *Relationship.*

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 34–122 mm SL.

Body: depth 36.5–40.
Caudal peduncle: depth 9.0–10.4.
Head: length 28–30; depth 28.5–31.5.
Snout: length 6.0–7.5.
Eye: diameter 9.75–11.8.
Interorbital: width 3.6–4.1.
Maxillary: length 14.3–16.
Mandible: length 15.5–17.
Anal fin: length of base 37–43.
Pelvic fin: length 7.4–9.0.
Pectoral fin: length 18–21.5.
Distance from snout to origin of: dorsal 47–51.

Scales: *ca.* 33–37, usually lost in preserved specimens.
Ventral scutes: 25–27.
Fin rays: dorsal 15 or 16 (rarely 17); anal 36–42; pectoral 13–15.
Vertebrae: 39 or 40 (5 specimens).

Body deep, strongly compressed, its greatest thickness definitely less than a third of its depth, its greatest depth 2.5–2.75 in SL; the dorsal outline only slightly convex, the ventral outline strongly convex. Caudal peduncle strongly compressed, its depth 2.8–3.2 in head.

Scales mostly lost in preserved specimens; those from middle of side below anterior rays of dorsal definitely deeper than long, with about 3–7 vertical grooves, all except the posterior one interrupted, the margin of these scales irregularly indented. Ventral scutes strong, 19–21 (usually 20) in advance of pelvic fins and 6 behind them.

Head 3.33–3.55 in SL, its depth at vertical from crossgroove at occiput 3.15–3.5. Snout shorter than eye, with a slight median notch, 4.15–5.15 in head. Eye 2.55–2.8

in head. INTERORBITAL 6.5–8.35. CHEEK fully as long as deep. MAXILLARY rather narrowly rounded posteriorly, generally reaching nearly below middle of eye, 1.8–2.0 in head; a narrow bone with teeth between premaxillary and maxillary. MANDIBLE projecting strongly, its tip scarcely below dorsal outline of head, its margin within mouth rising strongly, 1.7–1.85 in head. GILL RAKERS at angle of first arch only about as long as pupil, apparently not increasing in number with age, 23–25 on lower limb. TEETH small, in a single series on mandible and premaxillary; a row of minute teeth on margin of maxillary; present in bands on palatines, pterygoids, and tongue.

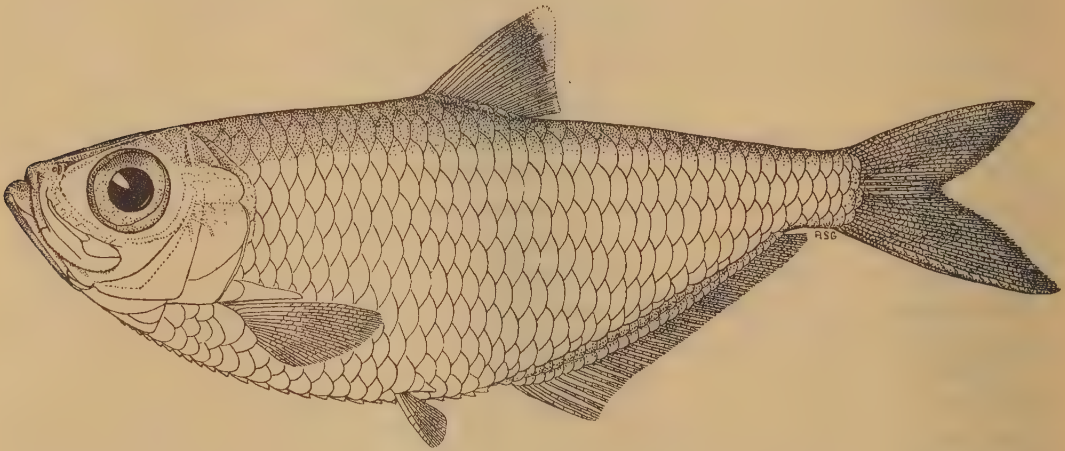

FIGURE 106. *Ilisha harroweri*, 160 mm TL, 123 mm SL, Colón, Panama, USNM 81749. Drawn by Ann S. Green.

DORSAL fin moderately elevated anteriorly, its longest rays reaching far beyond tip of last ray if deflexed, its origin a little nearer to margin of snout than to base of caudal, its distance from margin of snout 1.7–2.1 in SL; a sheath composed of one row of scales at base. CAUDAL fin forked, the lower lobe slightly the longer; small scales extending onto base of fin. ANAL fin long, its anterior rays somewhat elevated but not forming a definite lobe, its margin nearly straight, its origin somewhat variable, generally under posterior rays of dorsal, usually about equidistant between posterior margin of eye and base of caudal, its base 2.3–2.7 in SL; the sheath composed of two rows of scales anteriorly and one row posteriorly. PELVIC fin small, rarely missing, reaching halfway or more to origin of anal, inserted under, or more usually somewhat in advance of, vertical from origin of dorsal, much nearer to origin of anal than to base of pectoral, 3.1–3.8 in head; no free axillary process. PECTORAL fin moderately developed, not falcate, reaching base of pelvic in some but failing to reach it in others, its length 4.7–5.5 in SL, 1.3–1.65 in head; a free axillary process reaching about to midlength of longest rays.

Color. Bluish gray above. Sides silvery. Upper surface of anterior part of snout and mandible dusky. Dorsal and anal fins yellowish in life, the tip of the dorsal lobe and generally the margin of the caudal dusky; vertical fins with dusky punctulations.

Size. The largest example at hand is 155 mm (6.2 in.) TL and 122 mm SL. This specimen was among the larger ones seen in the Colón, Panama, market.

Development. Nothing concerning reproduction is known, and larval and postlarval stages have not been described. However, at hand are a few small specimens that are proportionately quite as deep as large ones. In two specimens, 34 and 50 mm SL, the depth equals 38.3 and 40 % of SL, whereas in the two largest, 115 and 122 mm SL, the depth equals 39 and 37.6 %; furthermore, the ventral profile is much more strongly convex anteriorly in the small examples. This is contrary to the usual development, as small specimens of this family ordinarily are slenderer than large ones. A development similar to that of *harroweri* has been noticed in *Brevoortia patronus.*

Relationship. It is not possible to distinguish this species from *Neosteus ternetzi* as described by Norman (*100*: 593) or by a comparison of two specimens from southern Brazil (Barro Santos, USNM 87718, Porto Inhuana, USNM 100837) with others from Colón, Panama, and Port-of-Spain, Trinidad. The following proportions and counts, which are generally in agreement with those given in the original description of *ternetzi* (from Panama and Trinidad), are based on the two specimens from Brazil, with the figures for the Barro Santos specimen first: Body depth 2.6, 2.75 in SL. Caudal peduncle depth 2.95, 3.1. Head length 3.4, 3.5; depth at vertical from cross-groove at occiput 3.15, 3.55. Snout length 5.0, 4.0 in head. Eye diameter 2.5, 2.7. Interorbital width 6.5, 6.55. Maxillary length 1.85, 1.8. Mandible length 1.85, 1.75. Anal base 2.4, 2.9. Predorsal distance 2.0, 1.95. Scales lost, about 35. Ventral scutes 18+6, 19+7. Fin rays: dorsal 16, 16; anal 36, 39; pectoral 15, 15. It seems proper to conclude, therefore, that *ternetzi* cannot be distinguished from *harroweri* specifically. It may be subspecifically distinct, but that can be determined only when more material becomes available for study.

Variation. The pelvic fins are well developed, but there is at hand a specimen 50 mm SL from Colón, Panama, in which these fins are missing. Inasmuch as no scar can be detected, it is assumed that it never possessed the fins. It seems highly probable that the specimen without pelvics, taken on the Atlantic coast of Panama and described as a new species by Borodin under the name *Pristigaster vanderbilti* (*19*: 6, pl. 1, fig. 1), also is this species. The occasional absence of pelvic fins in this species seemingly may be looked upon as a variation.

Range. Atlantic coast of Panama, Trinidad, and southern Brazil. Not reported as yet from intermediate points.

Synonyms and References:

Ilisha harroweri Fowler, Proc. Acad. nat. Sci. Philad., *69*, 1917: 128, fig. 1 (orig. descr.; type local. Colón, Panama; type ANSP 46959).

Neosteus harroweri Norman, Ann. Mag. nat. Hist., (9) *11*, 1923: 19 (descr. after Fowler).

Ilisha argentata Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 190, pl. 9 (orig. descr.; type local. Fox Bay, Colón, Panama; type USNM 81749).

Neosteus ternetzi Norman, Ann. Mag. Nat. Hist., (9) *12*, 1923: 593 (orig. descr.; type local. Rio de Janeiro, Brazil).

Pristigaster vanderbilti Borodin, Bull. Vanderbilt oceanogr. Mus., *1* (1), 1928: 6, pl. 1, fig. 1 (orig. descr.; type local. Limon Bay, Colón, Panama; type VOM 12; apparently based on an "abnormal" specimen of *Ilisha harroweri* without pelvics).

Ilishe (*Neosteus*) *ternetzi* von Ihering, Rev. Industr. Anim., 1 (3), 1930: 230 (fin rays, notes, Rio de Janeiro, Brazil).

Ilisha narragansetae Fowler 1911

Figure 107

Study Material. None.

Distinctive Characters. This species, according to the original description, seems to be related to *harroweri*, having a similar deep body and rather large scales. It seems to differ, however, in having a greater number of ventral scutes, more numerous anal and pectoral rays, and a longer pectoral fin.

Description. Proportional dimensions in per cent of standard length, and counts, condensed from Fowler (*38*: 208), specimen about 145 mm TL (caudal damaged), reported as taken off Newport, Rhode Island.

Body: depth 33.	*Scales*: *ca.* 44.
Head: length 25.5.	*Ventral scutes*: 32.
	Fin rays: dorsal 17; anal 45; pectoral 16.

BODY much compressed, its greatest depth at insertion of pelvic fin, 3.33 in SL; the dorsal outline slightly convex, the ventral outline more strongly convex anteriorly. CAUDAL PEDUNCLE compressed, its length a trifle less than its depth, 3.4 in head.

SCALES large, cycloid, each with as many as 6 vertical striae. VENTRAL SCUTES developed, 25 in advance of pelvics and 7 behind.

HEAD compressed, slightly concave above, convex below, greatly inclined, 3.5 in SL. SNOUT shorter than eye, a median notch scarcely developed, 4.3 in head. EYE 3.0. INTERORBITAL 6.25. MAXILLARY reaching somewhat beyond a vertical from anterior margin of pupil, 1.9 in head. MANDIBLE strongly projecting, its margin within mouth well elevated. GILL RAKERS half of length of eye, 22 on lower limb of first arch. TEETH small; a series on anterior part of mandible and premaxillaries, a double series on each palatine; also present on tongue.

DORSAL fin graduated downward from the first branched ray, its origin equidistant between tip of mandible and base of caudal. CAUDAL forked (damaged); small scales on base of fin. ANAL fin low, its margin straight, its anterior rays little elevated, its origin slightly behind base of dorsal, about equidistant between anterior margin of eye and base of caudal. PELVIC fin very small, inserted rather less than an eye's diameter in advance of vertical from origin of dorsal and much nearer to origin of anal than to base of pectoral. PECTORAL fin falcate, rather broad, reaching far beyond tip of pelvic fin, 1.3 in head.

Color. "Brownish on back and upper surface of head behind, sides and lower regions silvery white in alcohol; fins all pale brownish."

Range. Known only from the holotype, purported to have been taken at Newport, R.I. It is stated in the original account of this species, "it would appear undoubtedly to have been obtained at Newport as a waif of the Gulf Stream, probably from some tropical region in America." This remark dates back to 1911 and no other example like it has been reported since then. The genus, in fact, is not known from the West Indies (except Trinidad), nor from any other locality north of the Atlantic coast of Panama.

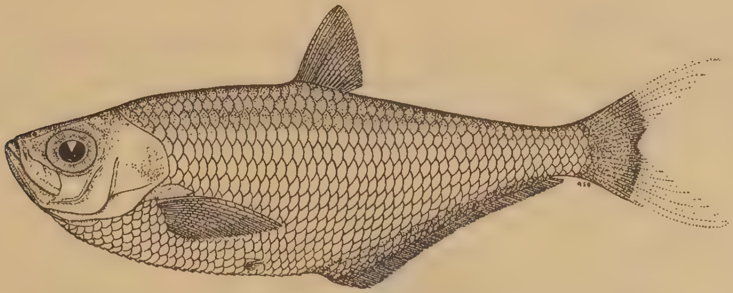

FIGURE 107. *Ilisha narragansetae*, about 165 mm TL (caudal damaged). Modified by Ann S. Green after Fowler, type, ANSP 15314.

Synonyms and References:

Ilisha narragansetae Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 208, fig. 1 (orig. descr.; type local. Newport, Rhode Island; type ANSP 15314; cf. *Pellona bleekeriana*, *Pristigaster flavipinnis*, and *Pellona castelnaeana*); Fowler, Proc. Boston Soc. nat. Hist., *35* (4), 1917: 112.

Neosteus narragansetae Norman, Ann. Mag. nat. Hist., (9) *11*, 1923: 20 (descr. after Fowler); Jordan, Manual Vert. Anim. NE U. S., ed. 13, 1929: 42 (diagn.).

Genus *Pristigaster* Cuvier 1817[52]

Pristigaster Cuvier, Règne Anim., ed. 1, *2*, 1817: 176; and *4*: pl. 10, fig. 3; type species by monotypy, figured but no specific name given; this same figure repeated in ed. 2 of Règne Anim., in which name *cayanus* is provided; generic type by monotypy, *Pristigaster* sp. Cuvier 1817 equals *P. cayanus* Cuvier 1829.

Characters. BODY strongly compressed; the dorsal outline straight to slightly convex; the chest and abdomen greatly dilated, forming a pronounced arc. SPINES on median line between occiput and origin of dorsal, 4 or 5. TEETH small; no canines. DORSAL fin small, with about 13–15 rays, its origin well in advance of origin of anal. ANAL fin long, its origin under or just behind base of last dorsal ray, with about 46–55 rays. PELVIC fin missing.

Remarks. The greatly dilated, rounded, half-moon-shaped outline of the chest and abdomen and the several short spines on the median line of the back between the occiput and origin of dorsal sufficiently characterize this genus.

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[52] Nomenclature and synonymy for both genus and species rewritten by G. S. Myers.

Range. Known from a single species, as herein understood, which ranges from the Guianas to northern Brazil and ascends freshwater streams.

Pristigaster cayana Cuvier 1829

Sardinha d'Agua Doce, Apapa (Brazil)

Figure 108

Study Material. None.

Distinctive Characters. In bodily shape, *cayana* resembles somewhat *Ilisha harroweri*, but its chest and abdomen are even more strongly convex, forming a very pronounced arc (see Fig. 108). The shape strikingly resembles that of the freshwater characin, *Gasteropelecus*, but its pectoral fin is much shorter.[53] The several spines on the median line of the back between the occiput and the dorsal fin separate it from all American species of the family.

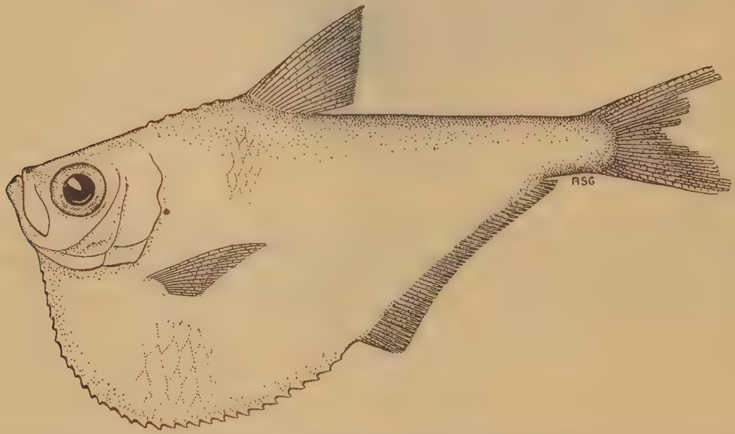

FIGURE 108. *Pristigaster cayana*, about 110 mm TL (caudal damaged). Drawn by Ann S. Green after Compos' *P. martii*.

Description. Proportional dimensions in per cent of standard length, and counts, from several published accounts, drawings, and a photograph.

Body: depth 50–56.
Head: length 25–29.

Scales: 39–42.
Ventral scutes: 30–33.

Gill rakers: on lower limb of first arch, 20–23.
Fin rays: dorsal 13–15; anal 46–55; pectoral 11.

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[53] Moreover it does not appear to possess the enormous pectoral muscles which enable the characin to buzz its wings during aerial flight.—G. S. Myers.

Body much compressed, its ventral outline strongly convex, forming a pronounced arc, its greatest depth over basal half of pectoral, 1.8–2.0 in SL. Caudal peduncle short, its depth 3.0 in head.

Ventral scutes prominent, especially the posterior ones. A median series of 5 spines between occiput and origin of dorsal.

Head 3.65–4.0 in SL. Snout shorter than eye, 3.5 in head. Eye 2.5 in head. Interorbital half of width of eye. Mouth almost vertical. Maxillary extending below anterior margin of eye, 2.5 in head. Mandible projecting, extending nearly into dorsal outline of head. Gill rakers slender, about 2.25 times in diameter of eye, 20–23 on lower limb.

Dorsal fin high anteriorly, its longest rays reaching far beyond tip of last ray if deflexed, nearly as long as head, its origin much nearer to margin of snout than to base of caudal. Caudal fin well forked, the lobes a little shorter than head. Anal long, its origin under or just behind last rays of dorsal, a little less than 0.5 of SL. Pectoral a little shorter than head.

Color. After Fowler: "Color in alcohol with back pale brown and under surfaces bright shining silvery white. Iris silvery white. Back and occiput with scattered dark to blackish dots. Dorsal and caudal yellowish buff basally, pale gray terminally. Other fins dull buff."

Size. A maximum length of only 110 mm (4.4 in.) has been reported.

Range. Coast of the Guianas to Brazil, ascending streams; reported from the Ucayali River Basin in the upper Amazon system, Peru.

Synonyms and References:

Pristigaster Cuvier, Règne Anim., ed. 1, *2*, 1817: 176 and *4*: pl. 10, fig. 3 (diagn. of genus and species combined; no specific name given; type local. "Seas of America"); Cuvier, Règne Anim., ed. 2, *3*, 1830: pl. 12, fig. 3 (no specific name on plate, but includ. in 1829 text; see under *P. cayanus* below).

Pristigaster cayanus Cuvier, Règne Anim., ed. 2, *2*, 1829: 321 (two spp. referred to; name *cayanus* provided for Amer. species figured in 1817; type local. fixed by specific name as Cayenne, French Guiana; fig. on 1830 plate of ed. 2 Règne Anim. ident. to that in ed. 1); Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 334, pl. 597 (descr., discus.); Günther, Cat. Fish. Brit. Mus., *7*, 1868: 463 (synon., descr., range); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 438 (descr. after Cuvier and Valenciennes, synon.); Starks, Stanf. Univ. Publ., 1913: 9 (Madeira R., Brazil, 400 miles above mouth); Norman, Ann. Mag. nat. Hist., (9) 11, 1923: 14 (synon., descr., range); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 45 (range, synon.); von Ihering, Rev. Indust. Anim., 1 (3), 1930: 230 (ref., diagn.); von Ihering, Dic. Anim. Brasil, 1940: 716 (habitat, notes); Eigenmann and Allen, Fish. West. S. Amer., 1942: 333 (Peruvian Amazon).

Pristigaster martii Agassiz, *in* Spix and Agassiz, Genera Species Pisc. Brazil., 1829: 55, pl. 24a (orig. descr.; type local. mouth of Amazon); Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 337 (presumed differences from *P. cayanus*; rec. for the mouth of Amazon); Castelnau, Anim. Nouv. Rares Amer. Sud, Poiss., 1855: 57 (Amazon); Fowler, Proc. Acad. nat. Sci. Philad., *91*, 1940: 221, fig. 2 (Rio Ucayali, Peruvian Amazon, synon., descr.); Campos, Arqu. Zool. estad. São Paulo (1941), *3* (7), 1942: 187, fig. 2 (synon., descr., geogr. distr.); Fowler, Arqu. Zool. estad. São Paulo, *6*, 1948: 16, fig. 6 (synon.).

Pristigaster americanus Guerin-Meneville, Iconogr. Règne Anim. Cuvier, Poiss., 1829–1844: 33, pl. 57, fig. 3 (type local. coast of S. Amer. in Atlantic).

Pristigaster phaeton Cuvier and Valenciennes, Hist. Nat. Poiss., *20*, 1847: 338 (orig. descr., type local. Amazon);

Castelnau, Anim. Nouv. Rares Amer. Sud, Poiss., 1855: 57, pl. 28, fig. 3 (based on material of Valenciennes).
Pristigaster cayana Myers, Copeia, 1956: 64 (nomencl., early synon. corrected).

Negative Reference:

Pristigaster martii Fowler, Bull. Amer. Mus. nat. Hist., *70* (1), 1936: 179, fig. 72 (synon. in part incorrect; descr. after *P. dolloi* Boulenger, which is not this species).

Genus *Odontognathus* Lacépède 1800

Odontognathus Lacépède, Hist. Nat. Poiss., *2*, 1800: 220; type species by monotypy, *Odontognathus mucronatus* Lacépède.

Generic Synonym:

Gnathobolus Bloch and Schneider, Syst. Ichthyol., 1801: 556; type species by monotypy, *Odontognathus mucronatus* Lacépède.

Characters. Body strongly compressed; the dorsal outline more or less concave over head, the ventral outline rather strongly convex anteriorly. Bony scutes on sharp keel of chest and abdomen, the outer margin of the posterior scutes more or less denticulate. Mouth strongly oblique to nearly vertical, with strongly projecting lower jaw. Maxillary greatly produced in large examples; maxillary and premaxillary separated by a toothless membranous section, forming a continuous (uninterrupted) margin with maxillary and premaxillary. Teeth small to minute, present on both jaws, palatines, pterygoids, and tongue, but wanting on vomer. Gill rakers not numerous, about 19–25 on lower limb of first arch. Dorsal fin rather feebly developed, with about 10–14 rays. Anal fin long, with about 52–80 rays, beginning far in advance of dorsal fin, generally well in advance of midlength of SL. Pelvic fins wanting. Pectoral fins generally longer than head.

Remarks. The species of this genus have greatly compressed bodies, a concavity over the head, a membranous section between the maxillary and premaxillary that forms a continuous margin with the two elements it separates, a very oblique to nearly vertical mouth, and a very long anal fin. Several of the posterior ventral scutes generally are denticulate.

Range. Known from both coasts of Panama, on the Atlantic side southward to Guiana.

Key to Species

1a. Depth of body 4.65 in SL; anal fin with 79 or 80 rays (71–82 by earlier descriptions); dorsal fin over middle of anal, its origin about twice as far from posterior margin of eye as from base of caudal. *mucronatus* Lacépède 1800, p. 431.

1b. Depth of body 3.5–4.25 in SL in adults; anal fin with only 52–60 rays; dorsal fin ending over middle of anal, its origin nearly twice as far from margin of snout as from base of caudal. *compressus* Meek and Hildebrand 1923, p. 433.

Odontognathus mucronatus Lacépède 1800

Figure 109

Study Material. Two large specimens, 135 and 152 mm TL, 111 and 136 mm SL, from Port-of-Spain, Trinidad, in only fair condition, the fins being more or less damaged and the color badly faded. Both specimens have the ventral scutes missing below the pectoral fins, causing a concavity in the ventral outline; this probably is an abnormality, even though it is present in both specimens.

Distinctive Characters. See *Relationship.*

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens, 111 and 136 mm SL.

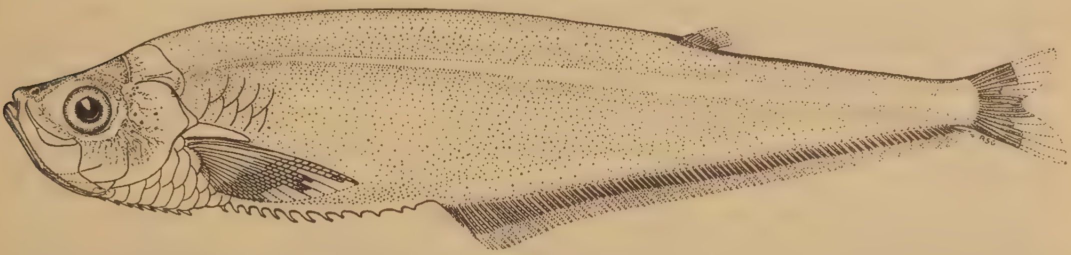

FIGURE 109. *Odontognathus mucronatus,* about 152 mm TL (caudal damaged), 136 mm SL, Gulf of Paria, Trinidad, USNM 123085. Drawn by Ann S. Green.

Body: depth 20.5–21.5.
Caudal peduncle: depth 5.1–5.4.
Head: length 17.5–19; depth 15–17.
Snout: length 4.7.
Eye: diameter 5.0–5.5.
Interorbital: width 1.5–1.9.
Maxillary: length 14–14.5.
Mandible: length 11–12.5.
Anal fin: length of base 52–56.
Pectoral fin: length 19–22.
Distance from snout to origin of: dorsal 70–71.5.

Scales: *ca.* 45–48 pockets, mostly lost in preserved specimens.
Ventral scutes: *ca.* 21 or 22 (some may be missing because of an abnormality).
Fin rays: dorsal 10–12; anal 79 or 80; pectoral 12.

BODY with greatest thickness about 0.25 of its depth, its greatest depth 4.65–4.8 in SL; the dorsal outline over head concave, the ventral outline moderately convex anteriorly and then concave (possibly abnormal). CAUDAL PEDUNCLE very short, its depth 3.4–3.5 in head.

SCALES nearly all lost, a few remaining over base of anal, these very thin, notably deeper than long, with nearly smooth margin and without vertical grooves. VENTRAL SCUTES rather prominent, all except the last 3 or 4 ending in prominent spines, the last ones with nearly smooth margin, missing for a short distance below base of pectoral (p. 432), forming a slight concavity.

HEAD small, its length 5.25–5.7 in SL, its depth at vertical from slight cross-groove at occiput 5.9–6.65. SNOUT a little shorter than eye, 3.75–4.05 in head. EYE 3.5–3.55. INTERORBITAL very narrow, 10–11.5 in head. CHEEK about as long as deep. MOUTH nearly vertical. MAXILLARY produced into a long narrow process reaching margin of opercle in larger one, 1.25–1.3 in head. MANDIBLE projecting strongly, its tip a little below dorsal outline, its margin within mouth rising strongly, forming a broadly rounded obtuse angle, 2.1–2.2 in head. GILL RAKERS fairly strong, only about half of length of eye, their inner margin rather strongly serrate, 24 or 25 on lower limb of first arch. TEETH all small to minute, in a single series on mandible, premaxillary, and maxillary; missing on membranous section between the last mentioned elements; minute teeth on palatines and pterygoids, but none on vomer; an elongated patch on tongue.

DORSAL fin small, feebly developed (damaged specimens at hand), its origin notably more than length of head behind origin of anal, about twice as far from the posterior margin of eye as from base of caudal, its distance from margin of snout 1.35–1.45 in SL. CAUDAL fin damaged, the lower lobe evidently the longer. ANAL fin very long, its origin nearer to tip of mandible than to base of caudal by about twice diameter of eye, its base 1.8–1.9 in SL. PECTORAL moderately large, a little longer than head, reaching 4th or 5th from last ventral scute, 4.55–5.25 in SL.

Color. Large preserved specimens pale; sides of head silvery. A pale lateral band (no doubt silvery in life), very narrow (a mere line), anteriorly, becoming fully half as broad as eye over posterior half of anal. Back with dusky punctulations extending forward onto head and snout and onto tip of mandible; punctulations also on fins.

Relationship. Compared to *O. compressus*, the body of *O. mucronatus* is more slender and apparently less compressed, the anal fin is longer, and the dorsal fin is more posteriorly placed. And in all these respects *mucronatus* is nearer to the Pacific *panamensis* than to *compressus*; however, it is even more slender than *panamensis*, and its gill rakers and anal rays are more numerous. If the interruption in the series of ventral scutes below the pectorals (p. 431) were normal, which seems doubtful, this would constitute another important difference that separates *mucronatus* from the other species of the genus. However, a slight concavity in the ventral outline has been noticed in a large specimen of *O. panamensis* and in a much smaller specimen of *O. tropicus* from northern Peru, recently referred to a new genus; however, in each instance the scutes are fully developed in the concavity. Other specimens of the same species have no such concavity in the ventral outline, nor do any of the numerous specimens of *O. compressus* examined. Furthermore, this question of abnormality is not answered in Norman's revision (*99*: 15), wherein he gave no information other than "Ventral scutes 8 + 12," which is in approximate agreement with the number of scutes before and after the interruption at the concavity on the specimens at hand. It may be significant, however, that in the description of *O. panamensis* in his revision, the number of ventral scutes is also written "13 + 16"; there certainly is no interruption in the series of scutes in the specimen of that species before me.

Range. Known from the coast of Guiana and from Trinidad (Port-of-Spain).

Synonyms and References:

Odontognathus mucronatus Lacépède, Hist. Nat. Poiss., *2*, 1800: 221, pl. 7, fig. 2 (orig. descr. under "L'odontognathe aiguillone," but a footnote gives the binomial *Odontognathus mucronatus*; type local., Cayenne, French Guiana); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 438 (descr., synon.); Eigenmann, Mem. Carneg. Mus., *5*, 1912: 447 (synon., diagn., Georgetown, British Guiana); Norman, Ann. Mag. nat. Hist., (9) *11*, 1923: 15 (synon., descr.); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 45 (ref. to orig. descr.).

Gnathobolus mucronatus Cuvier and Valenciennes, Hist. Nat. Poiss., *21*, 1848: 91 (descr.).

Pristigaster mucronatus Günther, Cat. Fish. Brit. Mus., *7*, 1868: 462 (synon., descr.).

Odontognathus compressus Meek and Hildebrand 1923

Figures 110, 111

Study Material. Numerous specimens, about 30–145 mm TL (caudal damaged on 30-mm fish), 23–123 mm SL, including the holotype and 25 paratypes, from the Atlantic coast of Panama, and a few lots from the Gulf of Venezuela.

Distinctive Characters. The nearest relative of *O. compressus* is *O. panamensis* of the Pacific coast of Panama, but these species differ in having 52–60 and 65–68 anal rays, respectively. Furthermore, in *compressus* the dorsal fin is notably in advance of the middle of the anal base, whereas in *panamensis* it is about over the middle of the anal fin. Its relationship with *O. mucronatus* is shown in the Key to Species (p. 430).

Description. Proportional dimensions in per cent of standard length, and counts, based on *Study Material*, specimens 23–123 mm SL.

Body: depth 23.5–28.5.
Caudal peduncle: depth 7.25–8.3.
Head: length 18–21; depth 18–22.
Snout: length 4.2–5.1.
Eye: diameter 5.25–6.25.
Interorbital: width 2.0–2.75.
Maxillary: length 12–16.
Mandible: length 9.3–10.2.
Anal fin: length of base 47–54.
Pectoral fin: length 21–25.
Distance from snout to origin of: dorsal 65–67.

Scales: lost, *ca.* 36–43 pockets.
Ventral scutes: 25–29.
Vertebrae: 46 or 47 (3 specimens).
Fin rays: dorsal 11–14, usually 11 or 12; anal 52–60; pectoral 12–14.

Body elongate, excessively compressed, its greatest thickness about 0.17 of its depth, its greatest depth 3.5–4.25 in SL; the dorsal outline of head concave in adults; the ventral outline strongly convex anteriorly. Caudal peduncle much shorter than depth, its depth 2.3–2.9 in head.

Scales mostly lost; very thin, deeper than long, with nearly smooth margin, without evident vertical striations. Ventral scutes well developed, the last 8–10 with serrate margin.

Head small, its length 4.75–5.5 in SL, its depth at vertical from slight cross-groove at occiput 4.5–5.55. Snout a little shorter than eye, 3.6–4.7 in head. Eye 2.9–

3.8. INTERORBITAL very narrow, 7.0–10 in head. CHEEK fully as long as deep. MOUTH nearly vertical. MAXILLARY broad, rounded in young, with an oblique margin in somewhat larger ones, ending under anterior half of eye, becoming produced into a narrow process in examples 65 mm SL and upward, extending to or beyond margin of opercle in large individuals, about 2.2 in head in small examples to 1.1 in large specimens.

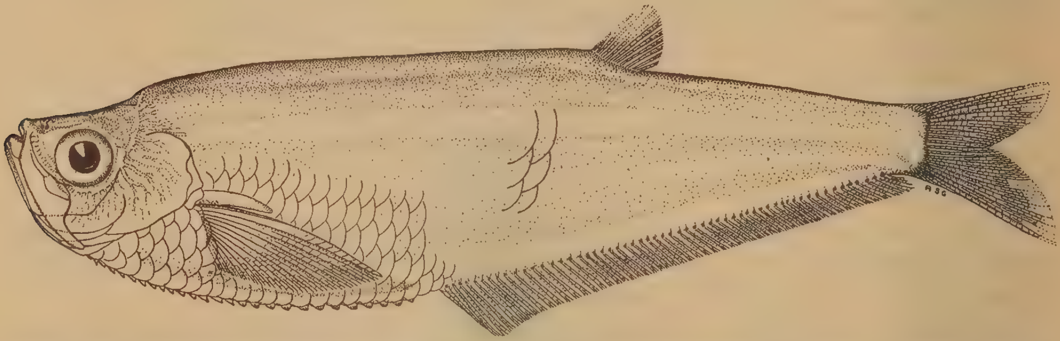

FIGURE 110. *Odontognathus compressus,* about 105 mm TL (caudal damaged), 88 mm SL, Colón, Panama, type, USNM 79533. Drawn by Ann S. Green.

MANDIBLE projecting strongly, its tip a little below dorsal outline of head, its margin within mouth rising abruptly, forming an obtusely rounded angle, 1.75–2.0 in head. GILL RAKERS rather slender, about half as long as eye, with rather well-developed serrae along inner edge, 19–23 on the lower limb. TEETH small to minute; apparently in a single series on mandible and on margin of premaxillary and maxillary but absent on membranous section between the last mentioned elements; minute teeth present on palatines, pterygoids, and on median section of tongue.

DORSAL fin small, rather feebly developed, more or less damaged in all specimens at hand, ending over middle of anal fin, its origin more than a head-length behind origin of anal, not quite twice as far from margin of snout as from base of caudal, its distance from margin of snout 1.5–1.55 in SL. CAUDAL fin rather broadly forked, the lower lobe the longer, about as long as head. ANAL fin long, its origin about an eye's diameter nearer to tip of mandible than to base of caudal, its base 1.8–2.1 in SL. PECTORAL fin a little longer than head, often reaching opposite to last ventral scute, sometimes failing to reach this point, 4.0–4.75 in SL; free axillary process about half as long as fin.

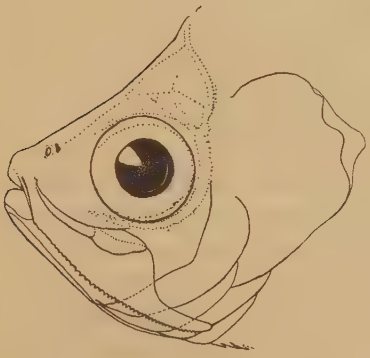

FIGURE 111. *Odontognathus compressus* head showing produced maxillary bone; same specimen as shown in Fig. 110. Drawn by Ann S. Green.

Color. Pale in alcohol. Sides of head silvery. Body with a silvery lateral band, about as broad as pupil. Back with dusky points and a median pale line in advance of dorsal; and a dark median streak behind it; margin of mandible and usually the snout behind premaxillary with a dark crossline; base of caudal with a dark crossline; base of anal with a row of dark dots; upper rays of pectoral with dusky points.

Size. This is one of the smaller of the excessively compressed herrings. The largest among the *Study Material* is 145 mm (5.7 in.) TL, 123 mm SL, which may be near the maximum.

Development. The body increases greatly in depth with age and growth, as in many other herrings. The depth in the smallest five examples at hand, 23–38 mm SL, is contained 4.1–4.7 in SL whereas this proportion in the five largest is 3.5–3.6. Furthermore, the dorsal profile anteriorly is about straight in the small specimens but concave in the large ones. The maxillary, as indicated in the *Description*, is short in small examples but becomes produced in large adults; in the smaller examples it is broadly rounded posteriorly and reaches under the anterior half of the eye; at about 50 mm SL it is no longer rounded posteriorly and has an oblique margin; as growth proceeds, the lower angle of the oblique margin becomes longer and sharper, and at 65 mm SL it is already well produced. However, it is only in large examples, upward of 100 mm SL, that the narrow process reaches to, or even slightly beyond, the margin of the opercle.

Range. Known from the Atlantic coast of Panama, from the Gulf of Venezuela, and from Trinidad.

Reference:

Odontognathus compressus Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 194 (orig. descr., type local. Colón, Panama; cf. *O. mucronatus*; type USNM 79553).

Genus *Neoopisthopterus* Hildebrand 1948

Neoopisthopterus Hildebrand, Smithson. misc. Coll., *110* (9), 1948: 6; type species by original designation, *Odontognathus tropicus* Hildebrand.

Characters. Body slender, strongly but not excessively compressed; ventral outline anteriorly much more strongly convex than dorsal outline. Bony scutes moderately strong with entire (smooth) margin, the chest and abdomen with a sharp keel. Mouth moderately oblique, with slightly projecting lower jaw. Maxillary short (with no indication in the rather small specimens that it will become produced in adults, as in *Odontognathus*), anteriorly overlapping distal end of premaxillary. Teeth small, present on jaws, palatines, pterygoids, and tongue, but missing on vomer. Gill rakers about 17–21 on lower limb of first arch. Dorsal fin small, with about 13–16 rays. Anal fin moderately long, with about 39–48 rays, beginning a short distance in advance of origin of dorsal. Pelvic fin wanting. Vertebrae about 46 or 47.

Remarks. This genus is characterized chiefly by the structure and relative position of the bones in the upper jaw. In *Neoopisthopterus* the maxillary and premaxillary overlap, with the margin of the jaw interrupted at the point where the maxillary passes over the premaxillary. In related genera (*Odontognathus* and *Opisthopterus*) these bones are separated by a membranous toothless section, with the margin of the upper jaw continous. The genus differs further from the other genera that lack the pelvic in having fewer anal rays.

Range. Known from two species, *N. tropicus* from the Pacific coast of Panama and Peru and *cubanus* from Cuba.

Neoopisthopterus cubanus Hildebrand 1948

Figures 112, 113

Study Material. Six small specimens, 43–50 mm TL, 35–41 mm SL, apparently young adults not fully mature; collected at Havana, Cuba, and sent to the writer by Dr. Luis Howell-Rivero of the Museo Poey at Havana; USNM 143569 and 143570.

Distinctive Characters. N. cubanus is very closely related to *N. tropicus* Hildebrand (57: 94, fig. 19), known from Panama and northern Peru, from which it differs only in having somewhat fewer dorsal and anal rays (*cubanus*: D. 13 or 14, A. 39–43; *tropicus*: D. 14–16, A 43–48). Also, these fins are somewhat differently placed; in *cubanus* the dorsal originates slightly more than an eye's diameter behind the beginning of anal and about equidistant between the margin of the opercle and the base of caudal, whereas in *tropicus* it begins scarcely an eye's diameter behind the origin of anal and is about equidistant between the posterior margin of the eye and the base of caudal. The average number of gill rakers on the lower limb of the first arch apparently is lower in *cubanus* than in *tropicus* (respectively, 17–19, 18–21). This, then, is another instance of the rather common occurrence of "twin" species in the Atlantic and Pacific, generally found on the opposite coasts of the Isthmus of Panama. As the West Indian and Atlantic Panamanian faunas are largely identical, *cubanus* may be expected on the Atlantic coast of Panama and neighboring countries.

Description. Proportional dimensions in per cent of standard length, and counts, based on study specimens 35–41 mm SL.

Body: depth 17–21.
Caudal peduncle: depth 6.5–8.5.
Head: length 21.5–23.5; depth 18.5–20.5.
Snout: length 5.3–6.8.
Eye: diameter 5.5–6.8.
Interorbital: width 2.6–3.1.
Maxillary: length 13.2–14.8.
Mandible: length 12.8–13.7.

Anal fin: length of base 33–39.
Distance from snout to origin of: dorsal 60–64.

Scales: lost, *ca.* 43 pockets.
Ventral scutes: 23–28.
Fin rays: dorsal 12–14; anal 39 to 43; pectoral 13.
Vertebrae: 47 (1 specimen).

Body elongate, strongly but not excessively compressed, its greatest thickness between a third and a fourth of its depth, its greatest depth 4.75–5.75 in SL; the dorsal outline of head straight to slightly convex; the ventral outline rather strongly convex anteriorly. Caudal peduncle shorter than deep, its depth 2.6–3.4 in head.

Scales mostly lost; rather large, very thin with smooth edge, and without evident striations. Ventral scutes well developed, all with entire (smooth) margin.

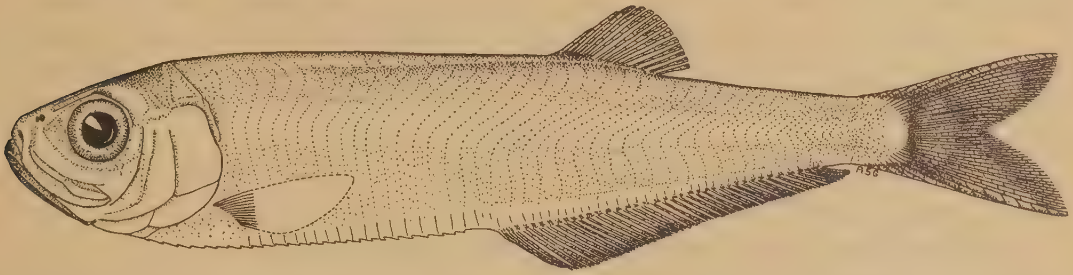

Figure 112. *Neoopisthopterus cubanus*, 50 mm TL, 41 mm SL, Havana, Cuba, type, USNM 143569. Drawn by Ann S. Green.

Head fairly short and deep, its length 4.25–4.65 in SL, its depth at vertical from slight crossgroove at occiput 4.9–5.4. Snout about as long as eye (in small specimens), 3.3–4.5 in head. Eye 3.4–4.1. Interorbital very narrow, 7.3–9.0. Cheek about as long as deep. Mouth moderately oblique. Maxillary quite narrowly rounded posteriorly, reaching to or somewhat beyond vertical from posterior margin of pupil, 1.55–1.8 in head. Mandible projecting slightly, its margin within mouth rising rather abruptly, 1.6–1.75 in head. Gill rakers slender, those at angle of first arch about as long as pupil, with very fine serrae along the inner edge. Teeth small to minute, apparently in a narrow band on anterior part of lower jaw; those on maxillary and premaxillary in a single series, interrupted at point of overlapping of maxillary and premaxillary; very small teeth on palatines and pterygoids and on median line of tongue.

Dorsal fin quite small, somewhat elevated anteriorly, its margin convex, its rays rather feeble, its origin rather more than an eye's diameter behind origin of anal and about equidistant between margin of opercle and base of caudal, its distance from margin of snout 1.55–1.65 in SL. Caudal fin rather broadly forked, the lower lobe slightly the longer, scarcely as long as head. Anal fin moderately long, its origin about equidistant between posterior margin of eye and base of caudal, its base 2.55–3.0 in SL. Pectoral fin damaged in all specimens at hand, apparently

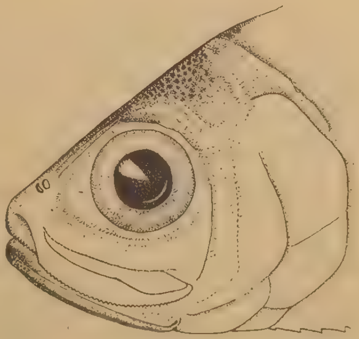

Figure 113. *Neoopisthopterus cubanus* head to show overlapping maxillary and premaxillary bones; same as shown in Fig. 112. Drawn by Ann S. Green.

rather large, inserted below margin of opercle, and about 1.5 times farther from origin of anal than from tip of mandible.

Color. Pale in alcohol. Side with a whitish band (no doubt silvery in life) about half as broad as eye. Upper surface of head brownish posteriorly, with rather large dusky dots; dusky dots on margin of snout medianly and on mandible anteriorly; median line of back also with scattered dusky dots; dusky points on base of caudal forming an oblique dark crossline and extending onto outer rays of fin; base of anal with a row of dark spots, with fine punctulations on the fin, chiefly near the margin.

Size. This species belongs to a group of herrings that attains a small size, few exceeding a length of 150 mm (6 in.). The known specimens of *cubanus* are all small (apparently immature). A specimen of the closely related Pacific *N. tropicus*, which seemingly is mature, is 66 mm SL or about 77 mm TL (3.1 in.), the caudal fin broken. It may be conjectured, therefore, that *N. cubanus* attains a length of only about 75–100 mm (3–4 in.).

Range. Known only from the type locality, Havana, Cuba.

Reference:

Neoopisthopterus cubanus Hildebrand, Smithson. misc. Coll., *110* (9), 1948: 7, figs. 3 and 4 (orig. descr.; type local. Havana, Cuba; type USNM 143569; cf. *N. tropicus* of the Pacific).

Genus *Chirocentrodon* Günther 1868

Chirocentrodon Günther, Cat. Fish. Brit. Mus., *7*, 1868: 463; genotype by monotypy, *Chirocentrodon taeniatus* Günther equals *Pellona bleekeriana* Poey. Myers, Copeia, 1929: 1; *Medipellona* a synonym. Breder, Copeia, 1942: 134; relationships.

Generic Synonym:

Medipellona Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67* (11), 1926: 417; genotype by original designation, *Pellona bleekeriana* Poey.

Characters. BODY slender, strongly compressed; ventral outline anteriorly much more strongly convex than dorsal outline. BONY SCUTES rather strong, about 24–28, the chest and abdomen with a sharp keel. MOUTH oblique, with moderately projecting lower jaw. TEETH on jaws, vomer, palatines, pterygoids, and tongue; each jaw (in adults) with two or more canines anteriorly. GILL RAKERS few, about 14–18 on lower limb of first arch. DORSAL fin small, with about 14–16 rays. ANAL fin long, beginning in advance of origin of dorsal, with about 39–43 rays. PELVIC fin very small, with 6 rays. VERTEBRAE about 44 or 45.

Remarks. This genus is characterized by the elongated and strongly compressed body with a strongly convex ventral outline anteriorly, the vomerine teeth, the canines anteriorly in each jaw, and the long anal fin beginning in front of the dorsal.

Discussion. *Chirocentrodon* generally has been placed in the family Clupeidae, but Jordan and Seale (75: 417), who evidently considered *Chirocentrodon taeniatus* Günther distinct from *Pellona bleekeriana* Poey (which has been disproved), erected a new genus

Medipellona on *Pellona bleekeriana* and doubtfully assigned it to the family Engraulidae (anchovies). Myers referred *Medipellona* to *Chirocentrodon* (*96*: 1). There seems to be no sound reason for removing from the Clupeidae this little herring, which has much in common with *Ilisha* (and *Neosteus*), but it apparently should be considered as having subfamily rank, Chirocentrinae, as already pointed out by Breder, who also discusses the possible relationship to *Chirocentrus*, an Asiatic genus (*22*: 136).[54]

Range. Known from the West Indies and from the Atlantic coast of South America from Panama to São Paulo, Brazil.

Chirocentrodon bleekerianus (Poey) 1867

Figures 114, 115

Study Material. Twenty-two specimens, *ca.* 52–107 mm TL (caudal fins damaged), 42–84 mm SL, including the holotype and paratype of *Ilisha caribbaea* Meek and Hildebrand (equals *C. bleekerianus*), and a cotype of *Pellona bleekeriana* Poey, in poor condition (USNM 120426); from Cuba; Jamaica; Puerto Rico; off Trinidad; at Fort Sherman (Toro Point) and Porto Bello, Panama; Pt. Macolla, Gulf of Venezuela; and Ubatuba, São Paulo, Brazil.

Distinctive Characters. The canine teeth in the anterior part of each jaw (in adults) are characteristic. The presence of vomerine teeth also distinguishes *bleekerianus* from all American Clupeidae, except the common Atlantic herring, *Clupea harengus.*

Description. Proportional dimensions in per cent of standard length, and counts, based on specimens 42–84 mm SL.

Body: depth 17.5–27.
Caudal peduncle: depth 7.8–9.5.
Head: length 22–26; depth 17–22.
Snout: length 5.7–8.2.
Eye: diameter 6.0–8.5.
Interorbital: width 2.9–4.5.
Maxillary: length 15–19.
Mandible: length 13.7–16.9.
Anal fin: length of base 35–39.
Pelvic fin: length 3.4–4.9.

Pectoral fin: length 14.8–18.5.
Distance from snout to origin of: dorsal 58–62.

Scales: lost, *ca.* 43 pockets.
Ventral scutes: 24–28.
Fin rays: dorsal 14–16, usually 15; anal 39–43, rarely 44 or 45; pectoral 13–15, usually 14.
Vertebrae: 44 or 45 (2 specimens).

BODY moderately slender, strongly compressed, its greatest thickness about a third of its depth, its greatest depth 3.85–5.55 in SL; the dorsal outline gently convex, the ventral contour strongly convex anteriorly. CAUDAL PEDUNCLE rather short, strongly compressed, its depth 2.55–3.7 in head.

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[54] Following Breder's excellent paper, there remains little doubt that *Chirocentrodon* is closely related to the two large Indo-Pacific species of *Chirocentrus* and that both genera should be placed together in a separate subfamily or family.—G. S. Myers.

Scales lost from specimens at hand; fairly large (judging from pockets). Ventral scutes strong, 15–19 (most frequently 16 or 17) before pelvic fins and 8–10 (usually 9 or 10) behind them.

Head 3.85–4.55 in SL, its depth at vertical from crossgroove at occiput 4.55–5.9. Snout generally about equal to length of eye, without a definite median notch, 3.25–4.0 in head. Eye 3.0–4.0 in head. Interorbital 6.0–8.2. Cheek triangular, rather longer than deep. Mouth moderately oblique. Maxillary rather strongly convex, narrow posteriorly, generally reaching vertical from posterior margin of eye, 1.25–1.55 in head. Mandible projecting moderately, its tip well below dorsal outline of head, its margin within mouth rising rather gradually, 1.45–1.75 in head. Gill rakers strongly serrate along inner margin, those at angle of first arch a little shorter than eye, not increasing in number with age, 14–18 (most frequently 15 or 16) on lower limb of first arch. Teeth prominent; an outer series of small teeth on mandible, with 1 or 2 canines on each side anteriorly forming an incomplete inner series; a somewhat irregular series on premaxillaries, with some of the anterior teeth (2 or 3 on each side) somewhat canine-like; a series of rather prominent slender pointed teeth, generally irregular in size, on margin of maxillary; a few pointed ones on vomer laterally; small teeth on palatines and pterygoids; and a narrow band of minute teeth on midline of tongue.

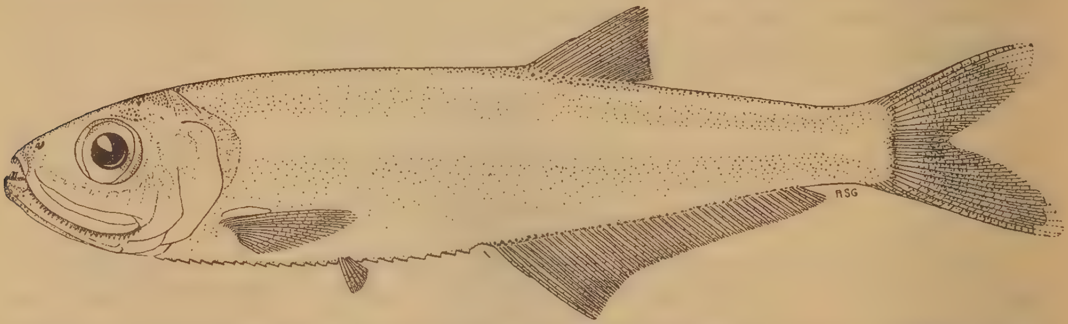

Figure 114. *Chirocentrodon bleekerianus*, about 87 mm TL (caudal damaged), 70 mm SL, Kingston, Jamaica, USNM 128274. Drawn by Ann S. Green.

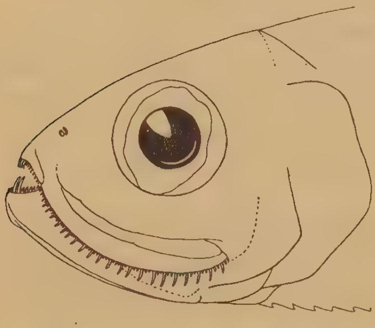

Figure 115. *Chirocentradon bleekerianus*, enlarged head showing teeth, same specimen as shown in Fig. 114. Drawn by Ann S. Green.

Dorsal fin small, not greatly elevated anteriorly, its longest rays generally reaching nearly or quite to tip of last ray if deflexed, its origin a little nearer to base of caudal than to posterior margin of eye, its distance from margin of snout 1.6–1.7 in SL. Caudal fin broadly forked, the lower lobe the larger, nearly as long as head (Fig. 114). Anal fin long, its anterior rays somewhat elevated, its origin about an eye's diameter in advance of dorsal, its base 2.5–2.95 in SL. PELVIC fin shorter than eye, inserted a little nearer to origin of anal than to base of pectoral, 5.4–6.9 in head. PECTORAL fin reaching well beyond base of pelvic, 5.4–6.75 in SL, 1.3–1.6 in head; the free axillary process about a third of the length of the fin.

Color. In alcohol, pale with a fairly definite white lateral band (presumably silvery in life); nape and tip of snout with dusky punctulations; the more recently preserved specimens with dusky punctulations on entire median section of back, mostly arranged in two parallel series behind dorsal fin; dorsal and caudal fins with dusky punctulations; base of anal generally with a row of small dark spots.

Size. This species is among the smallest of herrings. The largest at hand, about 107 mm TL (4.3 in.; 84 mm SL), seems to be the largest example known.

Development. Specimens less than 52 mm TL, 42 mm SL, remain unknown. Nevertheless, a considerable increase in proportionate depth takes place with age and growth, as the large specimens at hand are notably deeper than the smaller ones. The greatest depth in a specimen 42 mm SL is contained 5.7 times in SL whereas in one 84 mm SL this proportion is only 3.7.

Although proportionate increase in the body depth with age and growth is so usual among Clupeidae that it is expected, a proportionate increase in the size of eye during development is so unusual as to be subject to question. However, the specimens that are now at hand, suspected at first, did in fact show this characteristic. Using again the two extremes in size, it is found that the eye in the 42-mm specimen is contained 3.55 times in the head and is only 7.1 % of SL, whereas in the 84-mm fish it is contained 3.0 times in the head and is 8.3 % of SL. From the fairly complete and graduated growth series within the range already mentioned, it is evident that the eye does increase in proportionate size with age and growth. It may be assumed, therefore, that this development, the reverse of what usually obtains in fishes, is normal in *C. bleekerianus*.

Spawning. A female about 107 mm TL, containing well-developed eggs fully 0.5 mm in diameter, was taken off Trinidad by the ALBATROSS, in 31–34 fms. As it was caught on February 3 (1884), the indication is that *C. bleekerianus* spawns during the northern winter.

Relationship. This species, as now understood, is the only one belonging to the genus *Chirocentrodon*. It has been described under at least three different names, as indicated in the Synonyms, but Breder has shown adequately that the three constitute only one species (*22*: 133).

Commercial Importance. This little herring was seen occasionally in the market in Port-au-Prince, Haiti, by Beebe and Tee-Van, who also stated that it is rare in Haiti (*10*: 43). It is not known to be numerous anywhere, therefore its importance as food for man as well as for fishes and other animals feeding on fish is probably slight.

Range. West Indies, from Cuba, Haiti, Jamaica, Puerto Rico, and Trinidad; also from the Atlantic coast of Panama, the Gulf of Venezuela, and Ubatuba, São Paulo, Brazil.

Synonyms and References:

Pellona bleekeriana Poey, Repert. Fisico-Nat. Cuba, *2*, 1867: 242 (orig. descr.; type local. Matanzas, Cuba; cotypes MCZ 17845; one USNM 120426); Poey, Synop. Pisc. Cubens., 1868: 419 (ref. to orig. descr., notes); Poey, An. Soc. esp. Hist. Nat., *5* (2), 1876: 180, p. 148 in separate (common name, ref.); Howell-Rivero, Bull. Mus. comp. Zool. Harv., *82* (3), 1938: 171 (cotypes in bad condition).

Chirocentrodon taeniatus Günther, Cat. Fish. Brit. Mus., *7*, 1868: 463 (orig. descr.; type local. Jamaica, West Indies; types BMNH); Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 435 (descr. after Günther); Norman, Ann. Mag. nat. Hist., (9) *11*, 1923: 21 (descr., *P. bleekeriana* probably not distinct); Beebe and Tee-Van, Zoologica, N. Y., *10* (1), 1928: 43, fig. (refs., diagn., tables, size, local abund., Port-au-Prince, Haiti); Myers, Copeia, 1929: 1 (*C. bleekerianus* and *C. caribbaeus* probably distinct); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 45 (ref.).

Ilisha bleekeriana Jordan and Evermann, Bull. U. S. nat. Mus., 47 (1), 1896: 436 (descr. after Poey); Evermann and Marsh, Bull. U. S. Fish Comm. (1900), *20* (1), 1902: 86 (diagn.); Nichols, N. Y. Acad. Sci., *10* (2), 1929: 204 (distr., diagn., Puerto Rico).

Ilisha caribbaea Meek and Hildebrand, Field Mus. Publ., Zool., *15* (1), 1923: 191, pl. 10, fig. 1 (orig. descr.; type local. Porto Bello, Panama; type USNM 81769); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 45 (ref.).

Medipellona bleekeriana Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67* (11), 1926: 417 (descr. after Poey; relation.).

Medipellona caribbea Jordan and Seale, Bull. Mus. comp. Zool. Harv., *67* (11), 1926: 418 (diagn.).

Chirocentrodon bleekerianus Fowler, Proc. Acad. nat. Sci. Philad., *80*, 1928: 456 (descr., *taeniatus* Günther synon., Haiti); Jordan, Evermann, and Clark, Rep. U. S. Comm. Fish. (1928), 2, 1930: 45 (ref.); Breder, Copeia, 1942: 134, fig. 1 (synon., relation., descr.).

Genus *Dorosoma* Rafinesque 1820

Gizzard Shads, Threadfin Shad

By

Robert Rush Miller

Museum of Zoology

The University of Michigan

Dorosoma Rafinesque, West. Rev. misc. Mag., *2* (3), 1820: 171 (see Fowler, Monogr. Acad. nat. Sci. Philad., *7*, 1945: 6, 8); Ichthyol. Ohiensis, 1820: 39; type species by monotypy, *D. notata* equals *D. cepedianum* (LeSueur). Below falls of Ohio River.

Generic Synonyms:

Chatoessus Cuvier, Règne Anim., ed. 2, *2*, 1829: 320, in part; restricted by Cuvier and Valenciennes to *Megalops cepediana* LeSueur.

Signalosa Evermann and Kendall, Bull. U. S. Fish Comm. (1897), *17*, 1898: 127; type species, *Signalosa atchafalayae* equals *D. petenense* (Günther). Atchafalaya River, Melville, Louisiana.

Characters. Body compressed, silvery. The abdomen armed with Bony scutes; total 23–32. Scales cycloid, thin, 40–83 along side. Mouth small to moderate in size, terminal, subterminal, or inferior, the lower jaw included or jaws subequal. Snout short and rounded. Maxillary with two supramaxillary bones. Teeth absent in adult, but a row of fine teeth on upper jaw in young. Dorsal with last ray prolonged into a slender filament (absent or inconspicuous in young), thus resembling *Opisthonema*. Fin rays: dorsal 9–15, anal 17–38, pelvic 8, pectoral 12–17, caudal 19 (17 branched), rarely 17 or 18. Stomach gizzard-like, the Intestine long and much convoluted, with numerous Pyloric caeca. Vertebrae (including urostyle) 40–51.

Remarks. Dorosoma may be readily distinguished from *Opisthonema* in having (1) the ridge of the back before the dorsal fin naked rather than crossed by scales; (2) no bilobed dermal fold on the vertical anterior edge of the cleithrum; (3) an axillary scale, the pectoral fins not folding into a groove; (4) the dorsal origin not well in advance of the insertion of the pelvic fins; and (5) gill rakers 200–400 in *Dorosoma*, only about 65–109 in half-grown to adult *Opisthonema*.

Range. All species except *D. smithi* are confined to the Atlantic drainage of North and Middle America, from Canada to Nicaragua. They are found from southern South Dakota, Nebraska, and Minnesota, from the Great Lakes-St. Lawrence River Basin, and from about 40 to 41° N on the Atlantic seaboard (New York, New Jersey, and southeastern Pennsylvania) southward to Lake Nicaragua, but with a discontinuous distribution from northern Guatemala and British Honduras to Nicaragua. *D. smithi* is known only from coastal streams of northwestern México, in Sonora, Sinaloa, and Nayarit. Only two species, *D. cepedianum* and *D. petenense*, have been taken in brackish and salt water—the former from as far north as Sandy Hook Bay, New York, southward to the vicinity of Tampico, México.

Key to Species of *Dorosoma* Known from Brackish or Salt Water

1a. Mouth terminal; ventral edge of upper jaw smooth; fewer than 50 scales in lateral series, regularly arranged; anal rays 17–27, usually 20–25; prepelvic scutes 14–17 (rare); vertebrae 40–45. *petenense* (Günther) 1866, p. 448.

1b. Mouth subterminal or inferior; ventral edge of upper jaw with pronounced notch (except in young); more than 50 scales in lateral series, irregularly arranged; anal rays 25–36, usually 29–35, where sympatric with *D. petenense*; prepelvic scutes 17–20; vertebrae 48–51. *cepedianum* (LeSueur) 1818, below.

Dorosoma cepedianum (LeSueur) 1818

Gizzard Shad, Eastern Gizzard Shad

Figure 116

Study Material. Seventy-four specimens, 78–247 mm SL, for body proportions, 51–200 for meristic data except as otherwise stated, from various parts of its range, Canada to México.

Distinctive Characters. The comparatively small scales, 52–70 in lateral series and 36–45 around the body, a higher vertebral count (48–51, usually 50), the longer anal fin and greater number of rays (25–36), and preponderantly 18 + 12 ventral scutes, distinguish *D. cepedianum* from its sympatric relative *D. petenense.* Another relative, *Opisthonema oglinum*, may be separated from *D. cepedianum* by features listed in the generic account under *Remarks* (p. 443).

Description. Proportional dimensions in per cent of standard length and head length, with all measurements "stepped off" with a pair of precision dividers; based on *Study Material*, specimens 78–247 mm SL; counts based on 51–200 specimens, the number of specimens counted being given in parentheses.

Body: depth 2.3–3.1 in SL.

Caudal peduncle: length 2.4–3.5 and depth 2.45–3.4 in hl.

Head: length 3.0–3.9 in SL; width 1.8–2.5 in hl.

Snout: length 5.0–6.0 in hl.

Eye: length 3.3–5.4 in hl.

Interorbital: bony width 3.3–4.5 in hl.

Upper jaw: length 3.5–4.2 in hl.

Mandible: length 2.6–3.3 in hl.

Dorsal fin: base 1.85–2.6 in hl; length of filament 3.1–6.5 in SL, 0.8–2.0 in hl.

Caudal fin: length of lower lobe 0.7–1.1 in hl, typically longer than anal base (rarely subequal).

Anal fin: length of base 3.2–3.9 in SL, 0.75–1.25 in hl.

Pelvic fin: length 2.0–2.5 in hl.

Pectoral fin: length 1.15–1.45 in hl.

Distances: predorsal 1.85–2.05; prepelvic 2.0–2.35; anal origin to caudal base 2.4–2.8, all in SL.

Scales: lateral series 52–70, av. 61.06 (67), the first scale counted being the first above uppermost corner of gill opening; between dorsal and anal fins 19–24, av. 21.77 (52); around body 36–45, av. 41.03 (73), beginning with first one just in front of left pelvic fin; around caudal peduncle (slenderest part) 16–20, av. 18.02 (53).

Scutes: prepelvic 17–20, av. 17.99 (196); postpelvic 10–14, av. 11.76 (197); total ventral 27–32, av. 29.74 (196).

Gill rakers: on first arch, >300 at 65 mm SL, *ca.* 350 at 95 mm, and 412 at 157 mm; very numerous and fine (rakers counted *in situ*).

Fin rays: dorsal 10–13, av. 11.61 (197); caudal 19; anal 25–36, av. 31.32 (195); pelvic 8, rarely 7; pectoral 14–17, av. 15.52 (288; 144 fish).

Vertebrae: 48–51, av. 49.83, including urostyle (42).

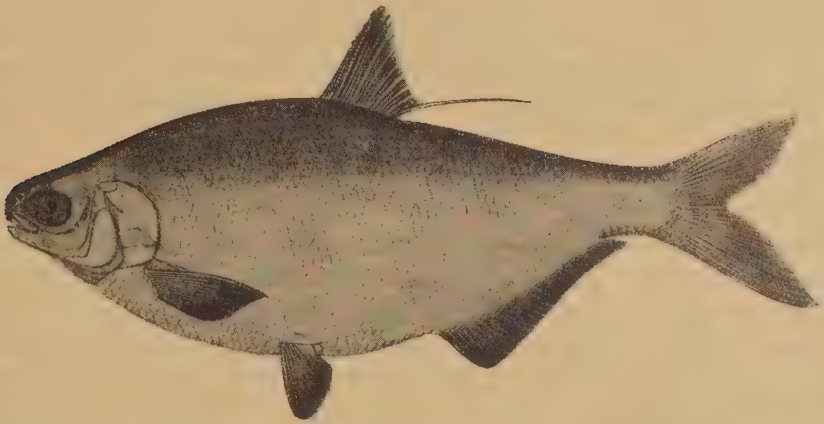

FIGURE 116. *Dorosoma cepedianum*, from Cumberland River, Tennessee, USNM 20034. After Goode, from drawing by H. L. Todd, somewhat emended.

No external characteristics will reliably distinguish the sexes.

Color. In life, body silvery. Bluish over back and upper sides but milky-white on abdomen, often with brassy or golden reflections from scales. About 6–8 horizontal, dark stripes along upper sides above level of middle of shoulder spot, extending from behind head to base of caudal fin. A large, round dark spot behind opercle lustrous purple, prominent in young and half-grown. Dorsal fin of adults nearly uniformly dusky; caudal fin dusky but darkened on its outer third; anal fin with outer 67 % dark, the basal third lighter, with melanophores sprinkled over most of fin; pectorals and pelvics with their outer halves darkened, grading to pale basally. Top of head, snout, upper jaw, and upper part of opercle pigmented in young and adult; the rest of head silvery. In young-of-the-year (up to about 4.5 in. TL), dorsal fin sparsely but uniformly sprinkled with chromatophores; caudal fin similar but with more pigment cells; anal, pectoral, and pelvic fins almost unpigmented.

Size. The Gizzard Shad is known to attain a total length of 20.5 inches but does not commonly grow longer than 10–14 inches. In a letter dated July 14, 1953, Mr.

Alfred Larsen (Fishery Biologist, Pennsylvania Fish Commission) wrote that specimens of *D. cepedianum* killed in Presque Isle Bay, Pennsylvania, early in 1953 ranged from 4 to 19 inches. Fish 10–13 inches long weigh about one pound, individuals 14–18 inches, 1–3 pounds; the heaviest recorded specimen weighed 3 pounds, 7 ounces (Trautman, *126*: 182).

Development and Growth. The prolarvae perform characteristic alternate sinking and rising movements for the first two days after hatching. The larvae are characterized by a long gut, 1.5–2.0 times the total length of the fish, by the retarded development of the single dorsal fin, and by the elongated anal fin with 22 rudimentary rays at 17.5 mm and 30–34 at 19–22 mm TL.

In contrast to the deep-bodied and strongly compressed adults, the very young are slender, cyprinid-like, and nearly cylindrical; the maxillaries have a few teeth on the lower edge which are lost with age, and unlike the adults with a highly specialized digestive tract, the young have an almost straight intestine and no pyloric caeca. By the end of the first summer of life the young possess the specializations of the adults.

At the end of the first summer, an average total length of about 4 inches is attained in Indiana and Ohio, 4.5 inches in the Chesapeake Bay region, and 5.0 inches in Tennessee and Oklahoma. The sizes in two Indiana ponds, after the first year, have been reported as follows: second summer, 7–9 inches, average 7.6; third summer, 9–11 inches, average 9.5; fourth summer, 9–12 inches, average 10.5; fifth summer, 10–13 inches, average 11.3; and sixth summer, 11–15 inches, average 12.8. Although they may live as long as 10 years, the life span is usually not more than seven years. In Lake Erie about 75 % of the annual growth of the Gizzard Shad takes place during the summer; in winter they grow little if at all and lose considerable weight.

Maturity typically occurs in the second or third year of life, at about 7–11 inches, but Vladykov (*127*: 35) has reported a mature female that was only 6 inches (151 mm) TL.

Spawning. Gizzard Shad are known to spawn only in fresh water, from late winter (mid-March) through most of the summer (at least to August 20) in sloughs, ponds, lakes, and large rivers. Spawning generally occurs on a rising temperature, usually between about 50° and 70° F. The creamy-yellow eggs, demersal and adhesive, are about 0.75 mm in diameter when fertilized and fixed. The embryos hatch after 95 hours of incubation at 62° F, or after about 36 hours at 80° F.

Precocious females appear to have few eggs. Those belonging to age-group II have the most, averaging about 380,000 eggs in five females 291 mm long; egg production then declines with successively older groups.

Food. Gizzard Shad are essentially filter feeders. Except for a few weeks after hatching, those in fresh water are almost entirely herbivorous, feeding heavily on microscopic plants, phytoplankton, and algae. After they reach a length of about 20–25 mm TL, the diet is remarkably alike at various sizes. The food habits in salt and brackish water have not been studied.

Habitat and Occurrence. Gizzard Shad inhabit large rivers, reservoirs, lakes, swamps, bays, barrow pits, estuaries, bayous, temporary floodwater pools along large river courses, sloughs, and similar quiet, open waters that may be clear to very silty. The very young apparently do not enter brackish water; in coastal rivers of Virginia the young occur in greatest abundance well upstream. In Chesapeake Bay, Gizzard Shad are common only during the fall months, occurring principally in brackish water near the mouths of freshwater streams, but in the rivers of that region they are common or abundant throughout the year. Along the Texas coast, they frequent the large brackish-water bays where individuals may be taken throughout the year in waters that vary in salinity from 2.0 to 33.7 $^{0}/_{00}$. Thus Gizzard Shad in this area also prefer brackish water to sea water. In general the smallest fish occur in the freshest water, with size increasing as salinity increases.

Dr. R. D. Suttkus of Tulane University has taken *D. cepedianum* at about 20 brackish and saltwater stations in Louisiana, not including nearly 40 separate captures from Lake Pontchartrain. Most of the 20 records are from along the Gulf of Mexico coast or within embayments connected with the Gulf. I am grateful to Dr. Suttkus for these data.

Range. Atlantic drainage of eastern North America south to Río Pánuco, México.

Synonyms and References:

Megalops cepediana LeSueur, J. Acad. nat. Sci. Philad., *1*, 1818: 361 (orig. descr.; markets of Baltimore and Philadelphia, hence usually given as Chesapeake and Delaware bays).

Clupea heterura Rafinesque, Amer. Month. Mag., 1818: 354 (orig. descr.; Ohio River).

Dorosoma notata Rafinesque, West. Rev. Misc. Mag., *2* (3), 1820: 172 (orig. descr.; type local., falls of Ohio R.).

Chatossus ellipticus Kirtland, Rep. Zool. Ohio *in* Second Rep. geol. Surv. Ohio, Columbus, 1838: 169, 195 (NOMEN NUDUM, Ohio; same as *D. notata*); Boston J. nat. Hist., *4* (2), 1842: 235, pl. 10, fig. 1 (orig. descr.; compar., occur. in Ohio, habits, mortal., Ohio R. and tributaries).

Megalops bimaculata LeSueur *in* Cuvier and Valenciennes, Hist. nat. Poiss., *21*, 1848: 104 (NOMEN NUDUM, synon. with *Chatoessus cepedianus* by Valenciennes).

Chatoessus insociabilis Abbott, Proc. Acad. nat. Sci. Philad. (1860), *12*, 1861: 365 (orig. descr.; habits, "sturgeon pond 2 miles below Trenton, New Jersey").

Chatoëssus cepediana Günther, Cat. Fish. Brit. Mus., *7*, 1868: 409 (descr., based on specimens from New York).

Dorosoma cepedianum exile Jordan and Gilbert, Proc. U.S. nat. Mus. (1882), *5*, 1883: 585 (orig. descr.; Galveston Bay, Texas).

Dorosoma cepedianum Goode, *et al.*, Fish. Fish. Industr. U.S., 1, 1884: 610 (in brackish or sea water, Atlantic coast); Higgins and Pearson, Rep. U.S. Comm. Fish. (1927), 1928: 42 (Pamlico Sound, N. Carolina); Hildebrand and Schroeder, Bull. U.S. Bur. Fish. (1927), *43*, 1928: 106 (Chesapeake Bay, rare in strictly salt water); Fowler, Monogr. Acad. nat. Sci. Philad., 7, 1945: 165 (Cape I. and rice field near Cordesville, S. Carolina); Gunter, Publ. Inst. mar. Sci. Texas, *1* (1), 1945: 30 (brackish and salt water, Texas coast; prefers brackish to sea water); Massmann, Trans. 18th N. Amer. Wildl. Conf., 1953: 439 (young in Virginia estuaries); Bailey, Winn, and Smith, Proc. Acad. nat. Sci. Philad., *106*, 1954: 120 (common in fresh tidewater, Escambia R., Florida); Miller, Fish. Bull. (173) U.S. Fish Wildl. Serv., *60*, 1960 (review of systematics and biol.); Minckley and Krumholz, Zoologica, N.Y., *44*, 1960 (hybrid. with *D. petenense*).

Dorosoma exile Meek, Field Mus. Publ., Zool., *5*, 1904: 94 (descr., lowland tributaries of Gulf of Mexico N. of Veracruz, México, San Juan, Forlón, Valles).

Dorosoma petenense (Günther) 1866

Threadfin Shad

Figure 117

Study Material. Twenty-five specimens, 59–180 mm SL, for measurements, and 186 for meristic data except as otherwise stated, from Florida to Lake Péten, Guatemala.

Distinctive Characters. The terminal mouth and the smooth ventral edge of the upper jaw distinguish this species from the other forms of *Dorosoma.* In addition it is readily separated from *D. cepedianum* in having larger, regularly arranged scales (fewer than 50 in lateral series), only 40–45 vertebrae, a smaller anal fin with 17–27 rays (usually 20–25), a longer and more pointed snout, longer upper jaw and mandible, and usually 16 or 17+9–11 ventral scutes. This species may be confused with *Opisthonema oglinum*, since both have a prolonged dorsal filament, but the latter is distinguished by the features given under *Remarks* in the generic account (p. 443).

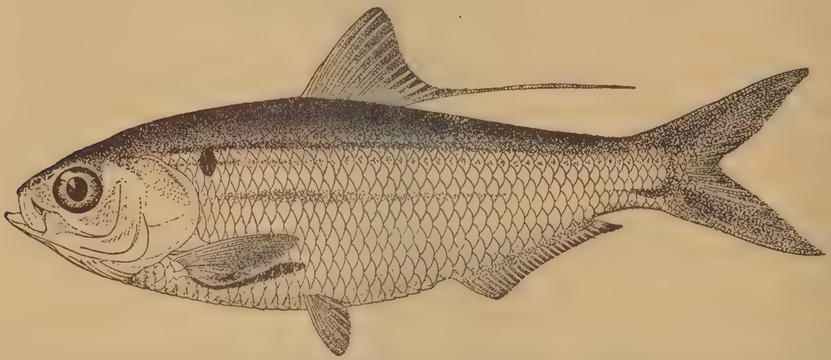

FIGURE 117. *Dorosoma petenense*, from Atchafalaya River, Alabama, USNM 48790. After Evermann and Kendall.

Description. Proportional dimensions in per cent of standard length and head length, with all measurements "stepped off" with precision dividers; based on specimens 59–180 mm SL; counts based on 186 specimens or less, the number of specimens counted being given in parentheses.

Body: depth 2.4–3.0 in SL.
Caudal peduncle: length 2.3–3.4 and depth 2.25–2.8 in hl.
Head: length 2.95–3.7 in SL; width 1.95–2.4 in hl.
Snout: length 4.1–4.85 in hl.
Eye: length 3.3–4.1 in hl.
Interorbital: bony width 3.5–4.5 in hl.
Upper jaw: length 2.8–3.35 in hl.
Mandible: length 2.1–2.5 in hl.
Dorsal fin: base 1.5–2.05 in hl; length of filament 2.7–3.1 in SL, 0.6–1.0 in hl.
Caudal fin: length of lower lobe 0.7–0.9 in hl.
Anal fin: length of base 3.5–4.35 in sl.

Pelvic fin: length 2.05–2.4 in hl.

Pectoral fin: length 1.2–1.35 in hl.

Distances: predorsal 1.9–2.25; prepelvic 1.9–2.25; anal origin to caudal base 2.6–3.1; all in SL.

Scales: lateral series 41–48; between dorsal and anal fins 14–17; around body 28–36; around caudal peduncle 16–20 (all counts based on 25 specimens covering the size range of this species).

Scutes: prepelvic 15–18, av. 16.79 (176); postpelvic 8–12, av. 9.95 (178); total ventral 23–29, av. 26.75 (176).

Gill rakers: *ca.* 300 at 66 mm SL, 330 at 117 mm, 350 at 131 mm, and about 440 at 180 mm; fine and numerous (rakers counted *in situ*).

Fin rays: dorsal 11–14, av. 12.13 (178); caudal 19; anal 17–27, av. 22.38 (179); pelvic 8, rarely 7; pectoral 12–17, av. 14.39 (354, 177 fish).

Vertebrae: 40–45, av. 42.23, including urostyle (30).

As in *D. cepedianum*, there appear to be no reliable external features that will distinguish the sexes.

Color. In life, body bright silvery, especially on sides, opercles, and underparts, but back and upper sides bluish-black or dark olivaceous, washed with gold and overlain with horizontal rows of dark stripes. A conspicuous, jet-black round or oval spot behind upper part of opercle. Caudal with middle portion of each fin lobe bright golden yellow, fading basally and distally, the posterior border dusky; dorsal fin dusky, washed with yellowish olive; anal fin intensely yellow; paired fins yellow basally. A broad golden stripe (often represented only by gilt reflections) in the light band between back and sides, but almost no gilt on sides of head.

Size and Age. The Threadfin Shad is a smaller species than the gizzard shad. In the northern part of its range, the adult generally does not exceed 5 or 6 inches TL; in southern states it may grow to 7 inches, and in Guatemala to nearly 8.75 inches or 180 mm SL (specimen from Laguna de Yalác; UMMZ 143386). The species has a short life-span, for few individuals appear to exceed two years of age.

Variations in Size with Season. In bays along the Texas coast, adults were most abundant in August and October while the young were entirely absent; between August and November the size increased from a mode between 103 and 108 mm TL to 118 mm. In January, only fish with a modal length of 63 mm came into the catch, and in February the same group was present along with a few fish 114 and 117 mm long. Possibly early growth takes place only in fresh water. Water temperatures in the bays of Texas varied from about 48 to 86° F over the year.

Spawning. Threadfin Shad may spawn when they are less than one year old; there appear to be two spawning peaks—spring and fall. Spawning occurs at about 70° F in open waters, near or over plants and other objects. The eggs are slightly adhesive.

Habits. Threadfin Shad are generally pelagic; they often feed and migrate in schools numbering thousands of individuals. The different age-groups usually remain in separate schools. They are known to concentrate at the downstream faces of dams and similar obstructions, and large aggregations are seen at reservoir inlets. Water current obviously attracts large schools; when the electric turbines were reduced or shut off in the Tennessee impoundments, the Threadfin Shad were difficult to find, but when the power was turned on they were present in abundance.

Food and Feeding. Like their close relative, these fish are plankton feeders, the major items of the adult diet consisting of algae (diatoms and unicellular green species), copepods, and cladocerans. Threadfin Shad introduced into the Salton Sea, California, have a preference for the fry of *Bairdiella icistius* (Jordan and Gilbert), which suggests that they may have similar food habits in coastal lagoons and estuaries within their natural range.

Tolerance to Temperature. As in the case of the gizzard shad, sudden temperature changes often produce high mortality among Threadfin Shad. Berry *et al.* have observed a spawning mortality for both species during April in Florida lakes. *D. petenense* cannot tolerate as low temperatures as *D. cepedianum*. For Threadfin Shad in the Colorado River, Texas, temperatures of about 54–58° F may be close to the minimum tolerance. However, among experimental individuals from the lower Tennessee River, subjected to water cooled from 50 and 60° F, there was a high mortality below 45°, with very few fish surviving below 40°.

Habitat and Occurrence. Threadfin Shad seek habitats similar to those of the gizzard shad and are often associated with *D. cepedianum* where the two species are sympatric. They live in bays, large rivers, reservoirs, lakes, estuaries, and other similar situations. Along the coast of Texas they occur in bays having salinities varying from 3.8 to 26.9 ‰, the majority having been taken in waters with salinities between 10 and 20 ‰. Apparently these fish show a preference for water that is neither fully marine nor very fresh, a condition typical in many lagoons along the coast of Texas. Larger fish, approximately 100–150 mm long, occurred in waters of about 15–30 ‰, whereas smaller fish, generally below 100 mm, were taken in salinities below 15 ‰.

Records of Threadfin Shad obtained by Dr. R. D. Suttkus through 1958 indicate their occurrence at nearly 50 brackish and saltwater stations in Florida, Alabama, Mississippi, Louisiana, and Texas, not including about 75 captures from Lake Pontchartrain.

Range. From the Ohio River of Kentucky and southern Indiana westward and southward to Oklahoma, Texas, and Florida, thence along the coast of the Gulf of México to northern Guatemala and British Honduras (Belize River). Their recent invasion of the Ohio River Basin is discussed by Minckley and Krumholz (*94*).

Synonyms and References:

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Chatoessus petenensis Günther, Cat. Fish. Brit. Mus., *7*, 1868: 408 (redescr. of types).

Chatoessus mexicanus Günther, Cat. Fish. Brit. Mus., *7*, 1868: 409 (orig. descr.; México, New Orleans, Louisiana).

Dorosoma mexicanum Jordan and Evermann, Bull. U.S. nat. Mus., 47 (1), 1896: 416 (descr., from Günther).

Dorosoma petenense Jordan and Evermann, Bull. U.S. nat. Mus., 47 (1), 1896: 417 (descr., from Günther); Regan, Biol. Centr. Amer., Pisces, *8*, 1906–08: 178 (redescr. of types); Fowler, Proc. Acad. nat. Sci.

Philad., *63*, 1911: 211 ("Panama," obviously in error); Bailey, Winn, and Smith, Proc. Acad. nat. Sci. Philad., *106*, 1954: 119 (range; from fresh tidal waters, Escambia R., Florida); Berry, Huish, and Moody, Copeia, 1956: 192 (spawn. mortal. in Florida, life-hist. notes); Kimsey, Calif. Fish Game, Inl. Fish. Adm. Rep., 58–16 (mimeo), 1958: 1–21 (life hist., proposed introd. into Sacramento–San Joaquin Delta); Shapovalov, Dill, and Cordone, Calif. Fish Game, *45*, 1959: 166 (review introd. into California).

Signalosa atchafalayae Evermann and Kendall, Bull. U.S. Fish Comm. (1897), *17*, 1898: 127, pl. 7, fig. 4 (orig. descr.; Louisiana and Mississippi; use as bait; type local., Atchafalaya R. at Melville, Louisiana).

Signalosa mexicana Meek, Field Mus. Publ., Zool., *5*, 1904: 94 (synon., descr., lowland streams trib. to Gulf of Mexico, México—Valles, Obispo, El Hule, Perez); Regan, Biol. Centr. Amer., Pisces, *8*, 1906–08: 178 (redescr. of types, range); Fowler, Proc. Acad. nat. Sci. Philad., *63*, 1911: 211 (Volusia, Florida); Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 310 (descr. 9 specimens, includ. types, from Louisiana to Centr. Amer.); Gunter, Publ. Inst. Mar. Sci. Texas, 1 (1), 1945: 31 (prov. ident., size range, temp. range, and salinity, Copano and Aransas bays, Texas).

Signalosa petenensis Regan, Ann. Mag. nat. Hist., (8) *19*, 1917: 310 (redescr. based on types); Hubbs, in Hubbs and Allen, Proc. Fla. Acad. Sci., 6, 1943: 116 (*S. mexicana* and *S. atchafalayae* synon. with *S. petenensis*); Miller, Proc. Okla. Acad. Sci. (1953), *34*, 1955: 33–34 (first rec. for Oklahoma); Riggs and Moore, Proc. Okla. Acad. Sci. (1957), *38*, 1958: 64–67 (Lake Texoma, Oklahoma and Texas); Minckley and Krumholz, Zoologica, N.Y., *44*, 1960 (chars., hybrid. with *D. cepedianum*, range).

Signalosa mexicana mexicana Weed, Field Mus. Publ., Zool., *12* (11), 1925: 142 (synon., char., basin of Rio Papaloapan, Veracruz and Oaxaca, México).

Signalosa mexicana campi Weed, Field Mus. Publ., Zool., *12* (11), 1925: 143 (orig. descr.; compar., type local. Resaca de la Guerra, on or near Media Luna Ranch, Brownsville, Texas).

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Signalosa atchafalayae vanhyningi Weed, Field Mus. Publ., Zool., *12* (11), 1925: 145 (orig. descr.; type local. Prairie Cr., 6 mi. SE of Gainesville, Florida).

Signalosa petenensis vanhyningi Hubbs and Allen, Proc. Fla. Acad. Sci., *6*, 1943: 116 (common name, habits, color, Silver Springs, Florida); Fowler, Monogr. Acad. nat. Sci. Philad., 7, 1945: 266 (synon., refs., Volusia, Florida); Parsons and Kimsey, Prog. Fish-Cult., 16 (4), 1954: 179–181, 1 fig. (distr., review of biol., use as forage fish).

Signalosa petenensis campi Fowler, Monogr. Acad. nat. Sci. Philad., 7, 1945: 22 (Rio Grande).

Signalosa petenensis atchafalayae Fowler, Monogr. Acad. nat. Sci. Philad., 7, 1945: 366, 372 (synon., refs., Avery I., Louisiana; Galveston, Texas); Hubbs, Copeia, 1951: 297 (min. temp. tolerance in Colorado R., Austin, Texas); Chance and Miller, J. Tenn. Acad. Sci., *27* (3), 1952: 218 (first publ. rec. for Tennessee Valley; effect of severe winter, 1950–51); Kimsey, Calif. Fish Game, *40*, 1954: 204 (introd. into California).

Dorosoma petenensis atchafalayae Kimsey, Trans. Amer. Fish. Soc. (1957), *87*, 1958: 331, 332 (forage use in California and Arizona).

Dorosoma petenense atchafalayae Haskell, Copeia, 1959: 298–302 (food habits, Arizona).

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Printed in Denmark for the Sears Foundation for Marine Research, Yale University, New Haven, Connecticut, USA.
Bianco Lunos Bogtrykkeri AS, Copenhagen, Denmark

Accumulation of Radioactive Gold by Estuarine Animals

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The accumulation of radioactive gold by estuarine animals was investigated in conjunction with a sediment tracing study conducted in the Cape Fear River, N. C. by the Corps of Engineers. Test animals, including blue crabs (*Callinectes sapidus*), oysters (*Crassostrea virginica*), mummichogs (*Fundulus heteroclitus*), and croaker (*Micropogon undulatus*), were placed in cages at 6 stations in the river. Samples of animals, water, and sediments were taken 1, 17, 41, and 144 hours after the release of sediment, labeled with radioactive gold, into the river. All samples contained low levels of radioactivity, including those taken directly from the drop zone. Currents and wave action quickly dispersed labeled sediment particles from the area so that the only detectable radioactivity associated with natural sediment occurred at station 2 in the drop zone. Oysters accumulated the most radioactivity followed by crabs and fish. No measurable amounts of activity were detected in the animals, sediment and water samples after 144 hours. It was concluded that the amount of radioactive gold used did not constitute a hazard to the marine community.

Abstract reprinted from the *ASB Bulletin*,
Vol. 10, No. 2, p. 30, April 1963.

WORLD SCIENTIFIC MEETING ON THE BIOLOGY OF TUNAS AND RELATED SPECIES
REUNION SCIENTIFIQUE MONDIALE SUR LA BIOLOGIE DU THON ET DES ESPECES VOISINES
REUNION CIENTIFICA MUNDIAL SOBRE BIOLOGIA DEL ATUN Y ESPECIES AFINES

LA JOLLA, CALIFORNIA, U.S.A., 2-14 July 1962

Methodological Paper No. 4

THE MATTER OF AVAILABILITY AND THE HARVEST OF TUNAS

By

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Reprinted from *Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species*, 2-14 July 1962, FAO *Fisheries Reports* (H. Rosa, Jr., Editor), No. 6, Vol. 3, 1963, pp. 1041-1055.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Rome, Italy
ORGANISATION DES NATIONS UNIES POUR L'ALIMENTATION ET L'AGRICULTURE, Rome, Italie
ORGANIZACION DE LAS NACIONES UNIDAS PARA LA AGRICULTURA Y LA ALIMENTACION, Roma, Italia

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Abstract

Problems associated with fluctuations in availability and variations in vulnerability of the commercially important tunas are described; present knowledge concerning these fluctuations is reviewed; and suggestions are made for future research. Variations in availability are shown to be troublesome in determining optimum harvest and to affect fishing success. Explanations and examples are provided of current research practices concerning them which are: to describe and associate features of the oceanic circulation and distribution of properties with occurrence of tunas; to interpret variations therein; and to develop empirical relationships of predictive value. Consideration of the vulnerability of tunas to fishing gear is restricted to general features of their behavior and to the potential usefulness of behavior research. Discussion of future research dwells on the need for intensive studies of temporal variations in the environment; the coupling of oceanographic and meteorological research; comprehensive oceanographic surveys; and the progressive shift to studies of dynamic processes. Concern is registered that the research required is excessive relative to the importance of existing fisheries but this is more than mollified by man's growing demand for increased knowledge of the ocean.

MP/4

THONS : DISPONIBILITE ET PRODUCTION

Résumé

La communication décrit les problèmes que posent les variations de la disponibilité et de la vulnérabilité des espèces de thons commercialement importantes, passe en revue les connaissances actuelles sur ces fluctuations, et présente des suggestions intéressant la recherche future. Les variations de la disponibilité compliquent la détermination du rendement optimal constant et compromettent les résultats de la pêche. A cet égard, l'auteur fournit des explications et des exemples des pratiques actuelles en matière de recherche: description des caractéristiques de la circulation océanique et de ses propriétés relativement à la présence de thons; interprétation des variations; établissement de rapports empiriques permettant de faire des prédictions. L'examen de la vulnérabilité des thons aux engins de pêche est limité aux caractéristiques générales de leur comportement et à l'utilité que peut présenter la recherche en matière de comportement. En examinant l'activité future dans le domaine de la recherche, l'auteur attire l'attention sur les points suivants: nécessité d'intensifier l'étude des variations chronologiques du milieu; association de la recherche dans le domaine de l'océanographie et dans celui de la météorologie; organisation d'enquêtes océanographiques approfondies; place de plus en plus importante accordée aux études des processue dynamiques. On s'est demandé si les travaux de recherche exigés ne sont pas excessifs par rapport à l'importance des pêches actuelles, mais cette objection ne résiste guère aux exigences croissantes en matière des connaissances océanographiques.

LA CUESTION DE LA DISPONIBILIDAD Y LA COSECHA DE ATUN

Extracto

Se estudian los problemas relacionados con las fluctuaciones de la disponibilidad y con las variaciones en la vulnerabilidad de los atunes de importancia comercial; se pasa revista a los conocimientos actuales sobre tales fluctuaciones y se formulan propuestas para investigaciones futuras. Se demuestra que las variaciones de la disponibilidad perturban la obtención de una cosecha óptima e influyen en el éxito de las actividades de pesca. Se proporcionan explicaciones y ejemplos de los actuales sistemas de investigación referente a las mismas consistentes en: describir y asociar características de la circulación oceánica y de la distribución de sus propiedades con la presencia de atún; interpretar las variaciones dentro de aquéllas; desarrollar relaciones empíricas de valor predictivo. El estudio de la vulnerabilidad de los atunes a los artes de pesca se limita a las características generales del comportamiento de aquéllos y a la utilidad potencial de las investigaciones sobre tal comportamiento. La discusión de las investigaciones futuras se basa en la necesidad de realizar estudios intensivos de las variaciones temporales del medio ambiente; la combinación de las investigaciones oceanográficas y meteorológicas; los reconocimientos oceanógraficos generales; y la orientación progresiva hacia los estudios de los procesos dinámicos. Se reconoce que la investigación que se considera necesaria es excesiva en relación con la importancia de las actuales pesquerías, pero esto queda contrarrestado con exceso por la creciente demanda por parte del hombre de un mayor conocimiento del océano.

1 INTRODUCTION

Year-to-year and season-to-season fluctuations that occur in the catches of many kinds of marine fishes are of concern to fishery scientists and the fishing industry alike. They complicate the task of determining the optimum harvest and they cause production costs to be higher than if the supply were uniform.

Determination of the optimum harvest of a fishery, usually considered to be the maximum sustainable yield, requires an understanding of the interrelationships among population size, fishing intensity, and average catch. Three principal elements operate to determine the catch: abundance of the species, its availability to capture, and amount of fishing. The means are at hand to measure changes in the amount of fishing effort and to account for its effects. Variations in availability and abundance present problems in biology and oceanography and are more difficult to identify and understand, much less measure. Availability, which is a matter of distribution and behavior, is suspected to vary widely for many of the tunas which range over vast regions of the ocean.

If fluctuations in availability and abundance cause problems in determining the optimum harvest by scientists, they are also frequently troublesome to fishermen. Variations in distribution and abundance are responsible for much time wasted in searching for fish and can even cause the complete failure of a fishery. Failure of the United States west coast albacore fishery from 1928 to 1938 almost certainly was an availability phenomenon. Effectiveness of fishing gear is dependent on the behavior of fish and, since behavior often varies with age and distribution, this is another aspect of availability which affects the catch.

Research to discover why tunas concentrate where they do, when they do, and to learn of other features of their behavior, is in its infancy but is receiving more and more support. The latter is fortunate because what little has been discovered demonstrates clearly that such research can make an important contribution to the strategy of fishing, the improvement of harvesting efficiency, and the basic problem of conservation.

The intention in preparing this background paper was to highlight present understanding concerning the availability of the commercially important tunas and to make suggestions concerning future research. The author was assisted in this task by his colleagues, Messrs. Glenn A. Flittner and James H. Johnson, who reviewed the manuscript and offered valuable suggestions.

2 THE PROBLEM

2.1 Definition of terms

Availability is not as well understood as some other terms used by fishery scientists. This may arise because quite different connotations are attached to it. Most frequent usage refers to the portion of the total population within the geographic range of the fishery. Another meaning refers to the behavior of the fish within the range of the fishery as this relates to capturing the fish. Marr (1951) and Ahlstrom (1959), among others, have discussed the terminology at length.

Ahlstrom's definitions are suitable for a discussion of tuna availability. He defined availability as the "portion (percentage) of the recruited population that is physically within the geographic range of the fishery during the fishing season," and removed the matter of behavior relative to the effectiveness of fishing gear. This special aspect of availability he called "vulnerability" and defined it as "accessability of the fish within the geographic range of the fishery to the efforts of fishing." The definitions imply measurement, but for the tunas at least, what is known so far about availability and vulnerability is qualitative rather than quantitative.

2.2 Availability

Changes in availability of fishes are a reflection of the response of a population to changes in its environment. Understanding these fluctuations, and other population fluctuations, for that matter, and measuring them, requires a fundamental knowledge of the interplay of pertinent atmospheric, oceanic, and biological processes. The chain of events which affects and controls the environment begins with the atmosphere. Changes in the atmospheric pressure field result in variations in wind stress. Variations in wind stress affect the surface circulation through changes in the velocity, depth and breadth and a multitude of other features of ocean currents. Currents affect the distribution of organisms at all trophic levels. Currents and wind determine the nature and strength of refertilization processes whereby cool nutrient-rich waters are brought from great depths to the surface. The replenishment of surface waters affects primary biological production which, in turn, affects secondary production at each trophic level up to the fishes, with varying lags in time and space.

Fishery scientists and oceanographers are far from understanding the interplay of atmospheric, oceanic and biological processes as they cause fluctuations in the availability and abundance of fishes and forecasting such fluctuations. The current practice is to concentrate on describing the oceanic circulation; to associate physical, chemical and biological parameters of the ocean with the occurrence of fishes; and to document and interpret changes in the distribution of the fishes in relation to changes in the properties measured and features described. The bulk of this activity, as far as the tunas are concerned, has taken place during the past ten or 15 years and has been concentrated in the Pacific Ocean. The result has been that the general surface circulation and distribution of properties have been much more thoroughly described than before and variations therein, among seasons and years, have begun to be appreciated.

During the course of this descriptive work, a few successful attempts have resulted in predicting where and when patterns associated with availability will occur. Admittedly, where ability to predict has been obtained, only partial understanding has been achieved. Nevertheless, the ability has had practical application and empirical relationships derived have become the basis of hypotheses to be investigated and tested.

The importance of fluctuations in availability, as they hinder understanding of the interrelationships of population size, fishing effort and average catch, and as they cause wide variations in total catch, varies among tuna fisheries. Availability can be a major factor when the fishery is carried out over only a portion of the migratory route of the species. Most fisheries for the so-called temperate tunas (albacore and bluefin) and many for the tropical skipjack are of this ty and, as a result, variations in availability appear, presently at least, to be more impo tant than variations in abundance in determi ing yields. Recorded failures and success in the seasonal fisheries of the United State west coast and the Japanese Home Islands a most certainly have been availability phenomena because they have not occurred concurrently (Uda 1961a), even though the two fisheries operate on the same Pacific-wide population.

Variations in availability are neither a apparent nor of equal concern, either to sci entists monitoring the dynamics of the population or to fishermen, in the important fish eries for the tropical yellowfin and bigeye tunas. This is because these fisheries tak place at all seasons and their geographic ex tent coincides, more or less, with the distribution of the population.

The two situations are well illustrated the companion tropical fisheries for yellowfi and skipjack in the eastern Pacific, about which more is known that any other tuna po lations. For the yellowfin, all evidence points to closely allied geographic ranges fo the population and the fishery, and scientist have arrived at an understanding of the average relationship among fishing intensity, population size and catch (Schaefer 1961a). Were there wide fluctuations in availability, or in other fishery-independent factors, the scientists concerned could hardly have reach their present understanding in the brief yea that they have been studying the fishery. I contrast, the same understanding has not be obtained for skipjack. This population appears to be greatly affected by variations in fishery-independent factors, of which availability would seem to be a major one (Schae fer 1961a, Fig. 9; Sette 1960, Fig. 162). T skipjack situation appears to be like that of the seasonal albacore fisheries; the geographic range of the population is more extensive than the area in which the fishery is prosecuted.

2.3 Vulnerability

Vulnerability of fish to capture within the geographic range of a fishery depends on the effectiveness of the fishing gear employed relative to the behavior of the fish. Aside from economic considerations, the geographic range is dependent on the characteristics of the vessels engaged, notably their range and carrying capacity.

Tuna fishermen, especially those of the United States and Japan, have, over the years, effectively improved the efficiency of their gear and extended the range of their fishing activity. The Japanese have enjoyed considerable assistance from fishery laboratories in these pursuits. Today, fishing for tuna takes place over most of the world's tropical and subtropical seas. Few areas remain inaccessible to fishing vessels, so it is unlikely that future attention, with respect to vulnerability to capture, will be focused as heavily on exploratory fishing. Rather, emphasis probably will be to improve existing fishing methods and to develop new and more effective ones. Special attention is bound to be given to the tuna resources which are not now subject to exploitation because existing gear is ineffective, such as for the surface skipjack resources in vast areas of the tropics.

Scientists are expected to make important contributions to the improvement of fishing through behavior studies. Many believe that the elucidation of patterns of behavior can help make existing fishing methods more efficient and suggest more effective means of harvesting.

3 AVAILABILITY AND OCEANOGRAPHY

During the past 15 years or so, several broad investigations of the relationships between the tunas and their oceanic environment have been initiated in various parts of the Pacific Ocean. Schaefer (1961b) has summarized the important tuna oceanography programs of the central and eastern Pacific, and the activities of important Japanese laboratories in the western Pacific were described by the Fisheries Agency of Japan (1959). These investigations are providing the beginning of understanding of some relationships of tunas to their environment.

Studies of the broad geographical distribution of tuna catches from logbook records of fishing vessels by the Nankai Regional Fisheries Laboratory and the Inter-American Tropical Tuna Commission have demonstrated clearly that tunas are not distributed evenly over the ocean but tend to concentrate in certain specific areas. Whereas, concentrations in these specific, but vast, regions are remarkably consistent, there are notable variations from year to year and season to season in the locations of centers of good fishing within these broad regions. Enough has already been learned to identify some features of the environment which control distribution, at least in part. Also, in the course of this research, empirical relationships have been discovered which have predictive value.

3.1 Relations to sea-surface temperature

Much attention has centered on studies of distribution and availability of the tunas in relation to sea-surface temperature. Such analyses have proved attractive because surface temperature observations are readily available over vast areas of the ocean, both historically and on a continuing basis. The wealth of data is accumulated routinely by merchant and naval shipping and by fishing vessels.

Sea-surface temperature observations have been compiled to show the geographic limits of the various tunas and in attempts to define their temperature range for fishing. These studies have contributed much to our understanding of variations in availability of the tunas. Relating surface temperatures to distribution and fishing success has proved more definitive when studied regionally than world-wide. Squire (1962) has drawn attention to differences between the surface temperature ranges of several species found in the Gulf Stream in the Atlantic and the ranges of the same species in other regions as provided by Uda (1959 1960). Hester (1961a) pointed out that any attempt to postulate some particular optimum temperature for albacore would have to explain the difference of several degrees in water temperature existing between the California troll fishery and the Japanese pole-and-line fishery. Inoue (1961) has recorded that surface temperatures around the Japanese Home Islands during the summer albacore pole-

and-line fishery are different from those encountered in the winter longline fishery for albacore in the central north Pacific and that albacore taken in the latter region are dominantly from wider age groups. As another example of the latter, it is not logical to pool observations from the area of the eastern tropical Pacific with those from the central and western tropical Pacific to show distribution or optimum fishing conditions for yellowfin in relation to surface temperature. In the former, there is a surface fishery and, in the latter two regions, yellowfin of considerably larger size are caught on longlines from well below the surface where the water is usually several degrees cooler than at the surface.

At their lower temperature extremes, all species of tuna almost certainly respond directly to marked changes and temperature may be a factor in determining their occurrence at the warm end of the scale. There are examples of fluctuations in tuna availability which can be explained solely on the basis of temperature at the lower limits of their tolerance but situations which may be caused by high temperature are less clear. Tunas in waters of higher latitudes may well prefer particular temperatures within the surface layer but most researchers agree that surface temperature does not directly influence the distribution and availability in tropical waters except near the upper and lower limits of tolerance. Surface readings in either case, of course, can be indicative of other features and phenomena known to affect aggregation, and this matter will be discussed in the next section.

Examples from particular tropical and temperate tuna fisheries illustrate our present understanding of the effect of variations in sea-surface temperature on availability of the tunas and our existing capability with respect to prediction:

Off Baja California (Mexico) and California, tuna forage organisms are abundant at all seasons, yet yellowfin and skipjack only occur seasonally in commercial quantities. Their summer occurrence coincides with the northward movement of the 20° to 21°C isotherm and they disappear from the region with its retreat (Blackburn 1962; Schaefer 1961b). In 1955, which was a cold year in the eastern Pacific, the two species and the 21°C isotherm penetrated poleward to 26° to 27°N latitude; by contrast, the northern limit extended to between 32° and 30°N in the warm years of 1958 and 1959.

Schaefer (op cit) has pointed out that there is a striking relationship between the tropical tunas and surface temperature off the coast of Peru and northern Chile. Besides the seasonal changes in surface temperature to which yellowfin and skipjack respond, much as they do off Baja California, there also occur in some years widespread invasions of warm surface water along the coastal areas normally occupied by cold, upwelled water of the Peru Current. In years when the latter phenomenon takes place, the so-called "El Niño" years, the tropical tunas are more widely and sparsely distributed and occur much farther to the south.

Fluctuations in availability of skipjack, caused by avoidance of low surface temperatures, have long been known for the western Pacific (Takayama et al 1934; Uda 1938). Annual fluctuations in the area of origin of the Japanese Home Islands' summer skipjack catch and its magnitude as reflected by landings in three prefectures, Muyagi (northern Honshu), Shizuoka (central Honshu), and Kagoshima (Kyushu), are related directly to the poleward march of the 20° to 21°C isotherms. Robins (1952) has noted that the degree of southerly penetration of the skipjack seasonally along the east coast of Australia is related directly to temperature. Similarly, the northernmost limit of yellowin in the western Pacific in summer is typically about 35° N latitude but, in warm years, it extends past 40°N with a corresponding improvement in the availability of the species (Shapiro 1948).

Blackburn (1962) has suggested that unusually high temperatures may directly affect the availability of tropical tunas. Skipjack occur in varying abundance together with yellowfin along the coast of southern Mexico and Central America during the fourth quarter of the year (October-December). In the warm years of 1957 and 1958, skipjack were absent in the region of the thermal equator and yellowfin were appreciably less abundant. Examination of catch distribution charts (Alverson 1960) and surface temperature observations led Blackburn (op cit) to conclude that surface waters of 28°C are limiting for skipjack in the eastern Pacific and that yellowfin may also be affected by water this warm or warmer.

Albacore and bluefin range poleward annually as do the tropical species but their penetration into temperate waters is much more extensive. Seasonal fisheries supported by these migrations are subject to varying success in large part as a result of temperature-related variations in availability. This is hardly surprising. Sea-surface temperatures fluctuate widely in time and space at higher latitudes and these species occur in quantity only within particular temperature limits. Not only does temperature distribution affect the time and place in which these fisheries develop, their duration and the area encompassed, but it has also been found that there are optimum temperatures, within their range of tolerance, where these tunas are most available. Best fishing temperatures, for the albacore at least, vary with the age of the fish, time, area, and gear.

Surface temperature influences on seasonal fisheries for the temperate tunas are better known or, rather, better documented, for those off Japan and the North American west coast. The fact that temperature effects are similar suggests that they also are operative on temperate tunas in other regions of the world.

For the North American west coast, Johnson (1962a) has shown, using catch data of Clemens (1955), that the southern extent of best fishing for albacore is limited by about the 19°C isotherm, and Alverson (1961) has indicated that the Pacific northwest extension of the fishery is only successful when water is warmer than about 14°C. Johnson (1960) and Flittner (1961) have shown that the seasonal advance of the 15°C isotherm is accompanied by the northward distribution of albacore. Also, Hester (1961a) and Johnson (1962a, b) have demonstrated that the northern and southern extent and success of albacore fishing during the past 15 years were directly related to the seasonal march of the isotherms. The detailed temperature data for the area, for the period 1947-1958, were recently published by Johnson (1961).

Japanese scientists have demonstrated that the way in which the Home Islands' summer albacore fishery develops and the area it encompasses, is similarly controlled by seasonal warming (Inoue 1955,1961; Van Campen 1960). Inoue has pointed out that albacore avoid surface waters colder than 16°C, which corresponds closely with the lower limit of 15°C given by Uda (1961a, Fig. 1).

The striking effect that variations in surface temperature have on bluefin fishing by California seiners was shown by Hester (1961a, Fig. 1). In 1952 and 1953 (two years of cold water temperatures), the area of most productive fishing lay in the vicinity of Punta Eugenia, Baja California, whereas, in the warm years of 1957 and 1958, it centered along the southern California coast, some 500 miles to the north.

The range of optimum water temperature for albacore fishing off Japan during the height of the summer pole-and-line fishery is variously given as between 18° and 24°C (Uda and Tokunaga 1937; Sasaki 1939). Sasaki stated that, over a number of years, 50 to 80 percent of the catch was taken at 20° to 21°C. Clemens (1961) has provided similar and more detailed information for the west coast United States albacore fishery by vessels operating from California ports. His information for the years 1954-1958 shows that about 70 percent of the fish has been caught between about 16° and 19°C, with best fishing between 16° and 18°C. Examination of catch-per-day's fishing and temperature showed similar results but he found that there was variation with gear used and age of the fish. Live-bait or pole-and-line fishing proved somewhat better in warmer water than troll fishing and the former gear tended to be selective for larger fish. Alverson (1961) has discussed the matter of optimum water temperature in relation to albacore catch and gear off Oregon and Washington. He concluded that, although total catch records indicate that the optimum temperature for trolling is about 14° and 16°C, catch-per-unit-effort data do not indicate as marked a decline in availability at higher and lower temperatures as might be interpreted from total catch.

The mechanisms responsible for albacore being most available at specific surface temperature within the range of availability are not yet clear. Some are probably directly related to temperature but temperature is also a reflection of other features of the circulation responsible for concentrating the fish, some possibilities of which are discussed in succeeding sections.

3.2 Relations to food supply

It is well known that the oceans are not uniformly productive. Large regions, particularly in the tropics, do not support fish in commercial quantities. Observations on the nature of occurrences of commercial concentrations of tunas have shown that they aggregate in particular locations. Beyond their direct response to surface temperature, and perhaps other factors not yet recognized, the important reference is their food supply. Therefore, much research attention is focused on understanding the systems of ocean currents and water masses, the distribution of their chemical and biological contents, and the physical processes which support biological production.

More is known about the occurrence of tunas, relative to circulation features and food supply, in subtropical and tropical waters than in temperate regions. Beyond the fact that more tuna oceanography has been conducted in the former, the nature of the tropical ocean may be contributing to quicker understanding of the mechanisms involved. It is a two-layer system which, over vast regions, is characteristically stable. The upper mixed layer is separated from a lower layer by a strong thermocline and is not subject to regular renewal as occurs seasonally at high latitudes. Tremendous areas are, therefore, depleted of nutrients and are biologically barren. In particular places, however, winds and currents cause replenishment of the upper layer through upwelling, vertical mixing, or thermal anticline situations. Such areas are rich in nutrients and biological productivity is high, beginning with the phytoplankton and culminating with large crops of tuna forage organisms and the tunas themselves.

Schaefer (1961b), in his summary of the status of tuna oceanography programs in the eastern and central tropical Pacific, for the past 10 years or so, where such studies have been concentrated, has pointed out features and mechanisms responsible for tuna food being abundant in some places and not others. Three prominent features are upwelling, vertical mixing and variations to the circulation caused by land masses or underwater protuberances.

Mechanisms of enrichment in the mid-Pacific and the correspondence of tuna concentration have received lucid portrayal by Sette (1955, 1956). His description of the equatorial divergence-convergence system south of Hawaii is an authoritative example of the effect of upwelling on the availability of tunas. The stress of the southeast trades, and Coriolis force north and south of the equator, causes divergence of the South Equatorial Current along the equator. This, in turn, brings nutrient-rich water to the surface which moves westward and away from the equator. North of the equator, the upwelled water apparently sinks, forming a zone of convergence between the center of upwelling and the southern edge of the Equatorial Countercurrent. As a result of unequal wind stress along the equator, upwelling is more intense in the vicinity of 120°W longitude but zooplankton and tuna forage organisms are more abundant to the west and north, at 150° and 160°W longitude, because of the time lag in biological production and the westerly drift of the South Equatorial Current. Variations in the strength, duration, and other features of the southeast trades apparently are responsible for fluctuations in the extent of upwelling with resulting variations in availability and abundance of the tropical tunas.

Schaefer (op cit) and Blackburn (1961, 1962) have pointed out that coastal upwelling is responsible for high productivity and the consequent aggregation of tunas in the eastern tropical Pacific along the coasts of Baja California and Peru. Coastal upwelling during the winter months may also contribute to the refertilization of the Gulf of Tehuantepec but Blackburn (op cit) found that the dominant feature of this region is vertical mixing associated with gales, cyclonic circulation, and a thermal anticline also known as a thermal dome.

Thermal anticlines are found where the thermocline is elevated to a position close to the sea surface well within the euphotic zone (Cromwell 1956, 1958). Typically, they move around and change shape, and the water composing them is renewed by inflow from below; reason for their formation is not yet understood. High productivity off Costa Rica and at other areas, such as in the Panama Bight and off the southern Mexican coast between Cape Corrientes and Manzanillo, appears to be the result of persistent thermal domes.

Fishing records show that the tunas are more abundant in the vicinity of offshore islands and seamounts than in other adjacent regions. There is evidence that these protuberances affect the flow of currents and otherwise cause vertical mixing which results in enrichment of the euphotic zone. Sette (1955) was among the first to make reference to the part of islands in modifying the circulation and causing enrichment of the euphotic zone. He reported that perturbations within the North Equatorial Current as it passes through the Hawaiian Islands results in vertical mixing, as evidenced by large-scale and semi-permanent eddies downstream, and that concentrations of skipjack are associated with the complex system of eddies. Bennett and Schaefer (1960) discussed the effect on the surface circulation of the Revilla Gigedo Islands and Shimada Bank in the eastern Pacific and have shown that these features modify to some extent the distribution of physical and chemical properties and that eddying and upwelling occur downstream, as hypothesized by Uda and Ishino (1958). Although their study indicated some increase in productivity (C^{14} uptake) and surface chlorophyll near Clarion Island and Shimada Bank, zooplankton volumes were scarcely higher. They suggested that there is the possibility that benthic forms, which are herbivorous or detritus feeders, may contribute greatly to the food of tunas in such places.

Tunas tend to be abundant in the vicinity of fronts, places of surface temperature discontinuities, which mark boundaries between water masses or water types.[1] Fronts are large-scale features in the former case and small-scale in the latter. In either case, at such places, there is convergence which results in the accumulation of plankton and, in turn, larger organisms and the predatory fishes. Large-scale fronts have been discussed by Uda (1961b) among others, who has reported that albacore concentrate in eddies along the Oyashio-Kuroshio boundary, and Brown and Sherman (1961) have noted the association of skipjack with boundaries between water types around the Hawaiian Islands.

3.3 Relations to other factors

Research programs have suggested other factors and features related to oceanic circulation besides surface temperature and food supply that affect the distribution and availability of the tunas. The way in which they operate is not yet understood or, at best, is speculative. One such feature is worthy of mention. This is the association of tunas with water masses. Recent papers on this subject were those of Yamanaka and Anraku (1961) and Inoue (1961) which reported on the distribution of the important tunas in the north and south Pacific, west of 160°W longitude, in relation to water masses and water types, and those of Brown and Sherman (1961) and Seckel and Austin (1961) dealing with skipjack in the vicinity of the Hawaiian Islands.

Yamanaka and Anraku (op cit) were able to show that seasonal variation in the distribution of water masses and sub-types in the western Pacific, as described by temperature-chlorinity curves for the upper 200 m, were accompanied by similar variations in the distribution of several species of tunas. Research in the Hawaiian Islands has indicated that the skipjack is associated with the water of the California Current extension. The species occurs in commercial abundance seasonally when the islands are bathed by this water. No appreciable seasonal variation in food supply is associated with these variations in distribution, or is yet apparent.

3.4 Prediction

An important objective of oceanographic studies in relation to the availability of the tunas is to forecast where and when tunas will be available to commercial fishermen and in what quantities. Studies have not yet progressed to the extent necessary to attain fully this objective, nor are they likely to until there are better means, in terms of synopticity and continuity, of collecting data concerning the environment, and, in most cases, the catches. However, at the present time, techniques based on empirical relationships are being developed and some are in use to predict major shifts in distribution associated with broad-scale changes in the oceanic circulation. Since studies of small-scale features of the environment in relation to the localized aggregation and dispersal of the tunas have only begun, advances toward prognostication have been even less in this area.

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[1] Seckel (1962) has distinguished "water mass" from "water type." He considered that the latter is under the direct influence of physical processes taking place at the sea surface, whereas the former is not.

Because more is known about the distribution of the tunas in relation to sea-surface temperature, it is not surprising that prediction techniques, developed and so far in use, have been based on temperature. It is not surprising, either, that, in general, it is easier to predict the distribution of the temperate tunas than the tropical species.

Johnson (1962b) has investigated sea-surface temperatures and landings of albacore in Oregon and Washington and found that, in years of above normal temperatures, landings were significantly greater than in years of below normal temperatures. Whereas warm water did not insure a good fishery, widespread cold water apparently was detrimental to the success of the fishery. His study shows that, if the sea-surface temperature anomaly off the coasts of Oregon and Washington is large in June, it is possible to predict whether or not sea temperatures will be favorable for albacore at the normal commencement of the fishery in July.

Hester (1961a) has found that the general regions of best fishing, and total catch within prescribed confidence limits, for albacore and bluefin during the summer in waters off southern California and Baja California, can be forecast on the basis of the average sea-surface temperatures at two southern California shore stations during winter. Similarly, Inoue (1961) has discovered that the location and success of the summer pole-and-line albacore fishery off the mainland of Japan can be predicted with considerable accuracy from sea-surface temperature information obtained during the previous winter from the regions of the central north Pacific winter albacore longline fishery.

With reference to the association of skipjack with water of the California Current extension in the Hawaiian Islands, a technique has been developed using surface water temperature observations from an island shore station to predict the availability of this species to the seasonal fishery, despite the fact that surface temperature in the region of the fishing is at all times of the year above the minimum for commercial abundance (U.S. Bureau of Commercial Fisheries 1961; Brown and Sherman 1961). The procedure used is related to the time of displacement of the extension of the Kuroshio Current, which flows through the island chain in winter, by the northerly movement of the California Current extension in spring. The time of change occurs between early February and late March and is reflected by a reverse from cooling to warming. The time within this period that the change occurs is related to the total catch of skipjack landed during the subsequent summer.

The examples of prediction cited are concerned with broad-scale variations in availability as reflected by changes in distribution and have been possible because large-scale sea temperature anomalies usually persist for several months. The techniques employed have application to other tuna fisheries, especially to seasonal fisheries. Their refinement can be expected as studies of the underlying causes of temperature anomalies and variations in other features of the oceanic circulation progress and as more attention is given to understanding the effect of the atmospheric circulation on the ocean.

With respect to the localized aggregation and dispersal of the tunas, prediction is still a matter of the future. However, the sea-surface temperature charts routinely issued for regions of the eastern and western Pacific Ocean by the U.S. Bureau of Commercial Fisheries and the Japan Meteorological Agency, respectively, are of assistance to commercial fishermen in locating regions of optimum water temperature for fishing and for anticipating the movement and distribution of the tunas at the extremes of their range.

4 VULNERABILITY AND BEHAVIOR

Investigations of behavioral mechanisms of the tunas to understand and improve the effectiveness of fishing methods are recent in origin and few in number. The first such investigation began in 1957 when the U.S. Bureau of Commercial Fisheries, at its Honolulu Biological Laboratory, embarked on a program of study of the behavior of skipjack in the central Pacific. More recently, the Bureau initiated similar studies on the tunas of the eastern Pacific at its newly established San Diego Biological Laboratory. Before 1957, what little was known about tuna behavior had come from fishermen's observations and those recorded by individual scientists engaged in other endeavors.

Whereas the ingenuity of fishermen guarantees that fishing methods for the tunas will continue to improve, many scientists and fishermen are convinced that improvement could be accelerated if more were known about the behavior of these fishes, particularly about their feeding responses, schooling, association with other animals, and reactions to local physical features. It was this conviction that motivated the research begun at Honolulu and San Diego.

Any discussion of the behavior of the tunas relative to their vulnerability is certain to infringe on two other main agenda items scheduled for this meeting: (5) Physiology and Behavior, and (6) Fishing Methods. Since background papers have been prepared on these subjects, it is appropriate to confine this discussion to a few general features of the behavior of these fishes which affect their vulnerability and not dwell on what is known about the mechanisms responsible.

4.1 Relations to oceanographic features

Limitations and advantages of different fishing methods for the tunas are, in general, related to the distribution and behavior of the several species. We have seen that distribution is controlled by the oceanic circulation. In some respects, apparently, so is behavior. So little is known about the latter, however, that there are few examples to cite without being too speculative.

With respect to distribution, the live-bait fishing method is not effective where tuna fishing takes place far from where small bait fishes can be caught in quantity. Similarly, small vessels, no matter what gear is used, cannot fish far from land unless they operate from a mother ship. Beyond these special limitations and economic factors, of course, the advantages and disadvantages of the live-bait method and small boats are related largely to the behavior of the fish. As far as the other major fishing, purse-seining, longlining, and trolling, are concerned, the matter of behavior also appears to be the overriding factor in controlling their effectiveness.

One dominant behavioral characteristic of the tunas is that they live in the upper mixed layer of the open ocean. Differences in the penetration by the several species seem to be directly responsible for differences in the vulnerability of particular species to different gear.

In the tropics, purse-seine and live-bait methods are notably more successful along the eastern margin of the ocean where the mixed layer is shallow. In the eastern tropical Pacific, the thermocline is 20 to 70 m deep, depending on time and location. By contrast, longline fishing is the only method presently available which has proved successful for catching yellowfin and bigeye tunas in the tropics where the mixed layer is deeper (frequently well over 100 m), as in the central and western Pacific. These fishes apparently penetrate the entire range of the mixed layer. The wide-ranging skipjack must behave differently, though, and remain close to the surface whether the mixed layer be shallow or deep. Sightings of surface schools and the fact that longline gear is not effective for this species suggest this to be the case.

How variation in the thermocline depth within localized regions affects the vulnerability of tuna to particular gear is only now under investigation. Hester (1961b) describes some work begun by the U.S. Bureau of Commercial Fisheries at San Diego to determine the effective fishing depth of purse-seines and whether the thermocline depth and gradient affect the success of sets. This study has not progressed far enough to answer these questions but it has revealed that tunas will, under certain circumstances, enter the thermocline to escape capture by a seine.

There is great variation in the success of purse-seine sets for bluefin tuna. Purse-seining for albacore has not yet proved practical. In both circumstances, seining operations encounter pronounced thermocline variability over short distances and often at depths greater than those in the tropical regions where purse-seining is commonly practiced.

Whether the depth of the mixed layer is entirely or partly responsible for this difficulty or whether other behavioral characteristics pertaining to schooling are the cause requires investigation.

The way in which fishermen construct longline gear and the depth at which hooks are placed differ with species, locality and season. It may be that thermocline depth and corresponding responses of the several tunas require these modifications.

Murphy (1959) has reported that the numbers of albacore taken by gillnetting and surface trolling are markedly affected by the transparency of the water. Observations assembled from fishing cruises between Hawaii and the Aleutians and off the west coast of the United States showed that trolling efficiency was significantly better in clear water than in turbid water. The fact that live-bait fishing involves visual responses, as does trolling, may be one reason that purse-seiners have been, on the average, notably more effective than vessels employing the live-bait method in such areas as the Gulf of California where the water is more turbid. Catch records published by Alverson (1960) suggested this possibility even before recent improvements in seining techniques occurred.

4.2 Relations to behavioral characteristics

At the present stage of knowledge, discussion of behavioral characteristics of commercial fishes centers inevitably on what they do that makes them difficult to capture. Not much is known yet about why they do the things that they do.

Live-bait fishermen encounter all types of schools; likewise do albacore jig-boat fishermen and purse-seine fishermen. Some schools bite well, others bite poorly, and still others do not bite at all. Some schools are too scattered or move too fast to catch with either a purse-seine or live-bait. In certain areas, purse-seiners find that some schools are accompanied by so many porpoises as to make fishing operations extremely difficult. Since fishermen usually do not fish at night, schools located the afternoon before are often lost by morning. Do these schools maintain themselves at night? Can they be followed if they do? If fish are biting well at nightfall, can they be expected to bite the next morning? When can non-biting or non-feeding schools be expected to become feeding schools? When are scattered schools likely to become compact schools? These are only a few of the problems affecting vulnerability to fishing gear and only a few of the questions that need to be answered to assist fishermen in modifying their operational techniques and to suggest improvements to their gear. There are many others but we will leave this subject for further elucidation and for discussion of what is known about the behavioral mechanisms involved by those contributing to the two sessions previously noted.

5 FUTURE RESEARCH

In the span of 15 years, much progress has been made in our basic understanding of the scheme of things by which the atmosphere, the ocean and the biosphere are interrelated and how the interplay determines the distribution pattern of the tunas. Nearly all of the research effort has taken place in the Pacific Ocean. It has come about through broad surveys of the near-surface oceanic circulation and the distribution of physical, chemical and biological properties. It has been aided by constructing simplified descriptions of the atmospheric circulation considered to have major effect on the ocean circulation, and by averaging environmental and tuna catch data for broad regions over periods of months and even years.

So far, the research has provided a fairly adequate picture of the average distribution of the tunas in relation to general features of the oceanic circulation and the distribution of various properties. The results have not yet had any great impact as far as measuring and predicting fluctuations in availability and abundance of the tunas because temporal variations on both large and small scales have only begun to be studied and these studies have been confined largely to the examination of sea-surface temperature anomalies in temperate regions. Also, detailed studies of small-scale features of the circulation which appear to be important in the aggregation and dispersal of the tunas have only received casual attention. It is the study of temporal variations and small-scale features of the circulation which must now receive more attention if we are to understand, forecast, and eventually measure fluctuations in availability and abundance of the tunas.

5.1 Temporal variations

Much needs to be done in the study of temporal variations in the oceanic climate and corresponding changes in the distribution of the tunas. Perhaps the most urgent requirement is a better means of obtaining observations of environmental parameters and, in the case of most tuna fisheries, more detailed tuna catch and effort statistics, to better understand long-term and short-term variations.

Reliance on research ships for observations necessary to monitor temporal variations in the ocean is not satisfactory. It is not possible for a few research vessels to cover vast areas in a synoptic and continuous fashion; both features are essential. In instances where continuous observations have been possible, such as those at a station in the Hawaiian Islands for temperature and salinity (Brown and Sherman 1961), and where sea-surface temperatures have been available synoptically and continuously from merchant ships, as off the west coast of the United States, for example (Johnson 1962b), a great deal has been learned about temporal changes in the environment. At present, unfortunately, it is only possible to obtain synoptic time-series data of a few parameters at the sea surface from merchant ships and fishing craft. Few island and shore stations are in the right place, sufficiently widespread, or far enough offshore to provide adequate coverage. The cost that would be involved to obtain the observations required in both time and space would be prohibitive from research vessels. There is an urgent need for anchored stations at selected places which are capable of recording observations of as many parameters as possible at the sea surface and at intervals within the mixed layer and the thermocline.

The need for time-series data has been recognized by scientists other than those engaged in tuna oceanography. At the present time in the United States, considerable effort is being put forth by various groups to develop an inexpensive anchored unmanned buoy or data collecting device which will operate unattended for several months at a time and will store or transmit weather and oceanographic observations. The principal hindrance to its development has been the design of a satisfactory anchoring system. Instruments for recording some physical parameters are already available; attention is being given to sensors for other properties, including biological.

Operation of networks of unmanned data-collecting devices would make possible rapid advances in the study of temporal variations. O. E. Sette recently expressed the opinion (and many others will agree) that suitable monitoring systems alone, added to present research efforts, might well provide empirical understanding of some major problems concerning secular changes in the environment which give rise to major changes in the productivity of our fisheries.

Since the atmosphere and ocean are dynamic fluid systems affecting each other to a substantial degree, oceanographic investigations of temporal changes, particularly those of large scale, need to be coupled with meteorological studies. It is useful to draw attention to some of the work in this area to emphasize that more effort would be worthwhile. The Stanford Biological Laboratory of the U.S. Bureau of Commercial Fisheries in 1956 began research into the relation of ocean-wide pulses to long-term weather patterns over the Pacific Ocean. The research has brought to light data pertaining to ocean changes which, until now, have been neglected (Sette 1960). The Inter-American Tropical Tuna Commission recently supported, with encouraging results, an investigation of the meteorological control over the periodic occurrence of the "El Niño" condition off the northwest coast of South America (Bjerknes 1961). Uda (1960) has reported a reciprocal relationship between sea-surface temperatures in the regions of the seasonal albacore fisheries of the western and eastern Pacific. Roden and Reid (1961) have found some agreement between anomalous pressures over the Pacific and anomalous sea-surface temperatures. Investigations of this type are needed to hasten learning about the underlying causes of gross variations in ocean features.

5.2 Oceanographic surveys

The operation of networks of unmanned data-collecting devices most certainly will not eliminate the need for observations from oceanographic vessels. An urgent need remains for gross surveys to map basic biological properties such as productivity and standing crops as well as physical and chemical parameters in each of the major tuna resource areas. These can be accomplished satisfactorily only from moving platforms. In addition, there are numerous special research problems dealing with special features and processes in the ocean that require the use of properly equipped research vessels.

Although much attention has been devoted to gross surveys of such tuna resource areas as the eastern and central tropical Pacific, these surveys have been too fragmentary and discontinuous in time and space. In such regions, available pictures of the oceanic circulation, its processes and special features, and the consequent distribution of the tunas are grossly "average." They have been drawn by assembling and analyzing data taken by one- and two-ship expeditions over periods of several years. These "maps" now need to be drawn in more detail to reflect seasonal variations in a synoptic fashion. This implies that more research vessels must be engaged in future surveys so that the observations and the geographic scope may be much more comprehensive. A detailed outline of these requirements for the eastern tropical Pacific Ocean is provided in a 1961 report of the Eastern Pacific Oceanic Conference (EPOC). Those for other areas are similar.

5.3 Investigation of special features and processes

There is little disagreement that semi-synoptic surveys and monitoring of the ocean environment must occupy the major share of the research effort in most ocean regions for some time yet to advance our understanding of fluctuations in distribution, availability and abundance of the tunas and other living resources of the sea. Although these activities alone will not furnish complete understanding of the physical, chemical and biological regime, they can provide understanding of some major problems and they will reveal features and processes requiring detailed and long-term study both at sea and in the laboratory.

Whereas the time is not yet ripe in most regions to shift emphasis from charting and monitoring distribution of properties to the study of dynamic processes which produce the distributions and of the principles which govern them, the present state of knowledge makes it possible to suggest a number of special studies which may well go hand in hand with the survey work. Attention is already being given to a few, such as coastal upwelling; the local influence of seamounts, banks and isolated islands on the physical, chemical and biological regimes; physical, chemical and biological phenomena in relation to oceanic fronts and interfaces as they directly or indirectly cause the aggreation of fish; formation, persistence and structure of thermal anticlines and their effect on the overall circulation. A host of additional special studies are suggested in the EPOC report (1961) but their relative importance cannot be determined until the survey work is further advanced.

5.4 Behavioral investigations

Whereas additional oceanographic research is required to advance the understanding of fluctuations in availability of the tunas, there is a companion need for support of behavior studies, now in their infancy, for these investigations are expected to provide useful information in developing and improving fishing gear. We will defer making suggestions as to the direction behavior studies may take to the participants of the other two sections of the meeting previously mentioned.

5.5 Some special considerations

What has been suggested in the way of future research is a vast undertaking; the effort is many-fold greater than that now expended. The results would contribute equally to solving other problems concerning the tunas far broader than matters of availability and vulnerability and they would have tremendously wide application in advancing knowledge about other fishery resources. However, one cannot help but be concerned, as was Sette (1961), that the effort required may be quite out of line with the importance of existing commercial fisheries. Sette did go on to point out, though, that fluctuations of the ocean and its living resources are now of concern and importance far beyond present interests in fisheries, as did EPOC (1961) in its specific justifications for a comprehensive program of study of the eastern tropical Pacific Ocean. The increasing complexity of our civilization and the urgent problem of the world's rapidly increasing population both demand increased knowledge about the ocean and its resources.

The press for protein food in the world is great and will become even greater. The land will not supply this need but the ocean is known to have living resources far in excess of the few efficient high-seas fisheries such as the tunas. Harvest of these resources, however, awaits technological know-how which is dependent on more knowledge of the ocean and its resources. Modern meteorology requires better understanding of the interplay between ocean and atmosphere, for air-sea processes are of critical importance to extended weather forecasting and possible future weather control.

It would seem that fishery scientists and oceanographers can expect with reasonable certainty that increased support for oceanographic research, so vital to the advance of their endeavors and the interests of the industries they serve, will not depend solely on their requests but also will stem from the need for information for other important activities of mankind. Furthermore, the need for intensifying ocean research transgresses national interests. All nations should look forward to the pooling of research results and the integration of work at sea to advance the studies more rapidly.

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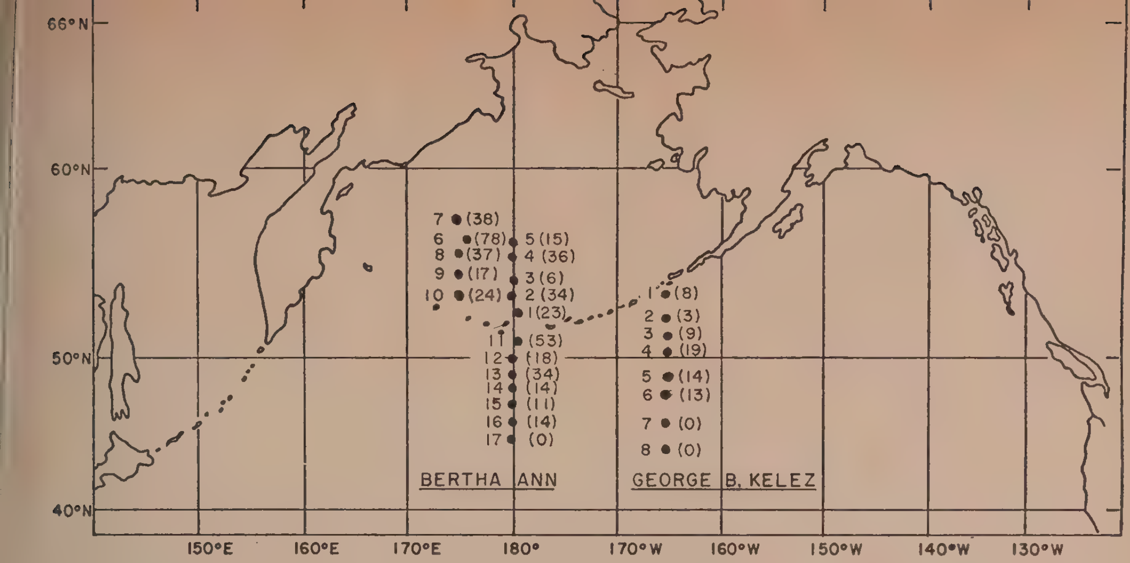


Winter research gillnetting results shown on this chart reveal catches of Red Salmon surprisingly far north for the first quarter of the year. Figures in parenthesis show the numbers of Red salmon caught at the fishing stations marked by dots and identified by plain numbers.

North Pacific and Bering Sea Winter Gillnetting

By

CHARLES HUNTER and HERBERT LARKINS

ast year the U. S. Bureau of Com- rcial Fisheries established a mile t by locating immature salmon dur- the winter in the North Pacific an (*Pacific Fisherman*, June 1962). s past winter another first was rked by finding salmon in the Ber- Sea. Fishing operations also took ce in the eastern and central North ific Ocean (see chart).

rom late January to early March charter vessel *Bertha Ann* with tain Mel Leonard as master, fished he western Bering Sea and central rth Pacific Ocean and the Bureau ned vessel *George B. Kelez* with tain Trygve Mathisen, master, ed the eastern North Pacific. These arch cruises are a part of the high research program conducted by Bureau of Commercial Fisheries the U. S. Section of the Interna- al North Pacific Fisheries Com- sion. Scientific personnel on these ses were: Charles Hunter, biolo- in charge of the *Bertha Ann;* Her- Larkins, biologist in charge of *Kelez;* James Ingraham, oceanog- her; Wendell Peterson, Rolf Hen- ks, and Don Fisk, biological as- nts.

he objectives of the cruises were study the distribution and abundance of salmon during the winter and to investigate the marine environment in the areas populated with salmon. Study of the salmon in its ocean environment during the entire year is important to the forecasting of spawning runs, the determination of ocean growth and mortality, and the knowledge of migration routes and feeding areas. All of the above factors are necessary for the management of the North American salmon resource.

- Sixteen hundred fathoms of surface gill net, 4 fathoms deep, was set each evening, weather permitting, and hauled in the morning after about 10 hours of fishing time. Four mesh sizes, 2½, 3¼, 4½, and 5¼″ stretched measure, were used to assure the capture of most sizes of salmon.

The area north and west of Adak Island was of particular interest because it was believed that salmon were not present in the Bering Sea during winter. However, Red salmon were caught at every fishing location (see chart), and at set Number 10 at 53° 30′N. and 175°E., two Chum salmon were also taken. The numbers of salmon in the Bering Sea catches were surprisingly uniform, indicating they are fairly evenly distributed throughout this area, although the ocean-age composition of the catches varied. Red salmon in their second-winter at sea and about 20″ in length, predominated at the southern stations and larger, three-winter at sea fish averaging 23″, were dominant in the north. Most 3-winter at sea and some 2-winter at sea Red salmon will spawn this summer. Small salmon, about 11″ in length, and in their first-winter at sea, were found only near the Aleutian chain south of 54° 30′N.

A total of 308 Red salmon was taken in the Bering Sea stations with the largest catch of 78 at Station 6. These Red salmon were fat and in very good condition, although for the most part their stomachs were empty when they were taken aboard. The food found in a few stomachs consisted of lantern fish, parts of squid, and various types of plankton. Plankton tows were not made on this cruise but there was little evidence that large quantities of plankton existed. Water temperatures ranged from 39°F. near the Aleutian Islands to 36°F. at the most northern station. Air temperatures were near freezing.

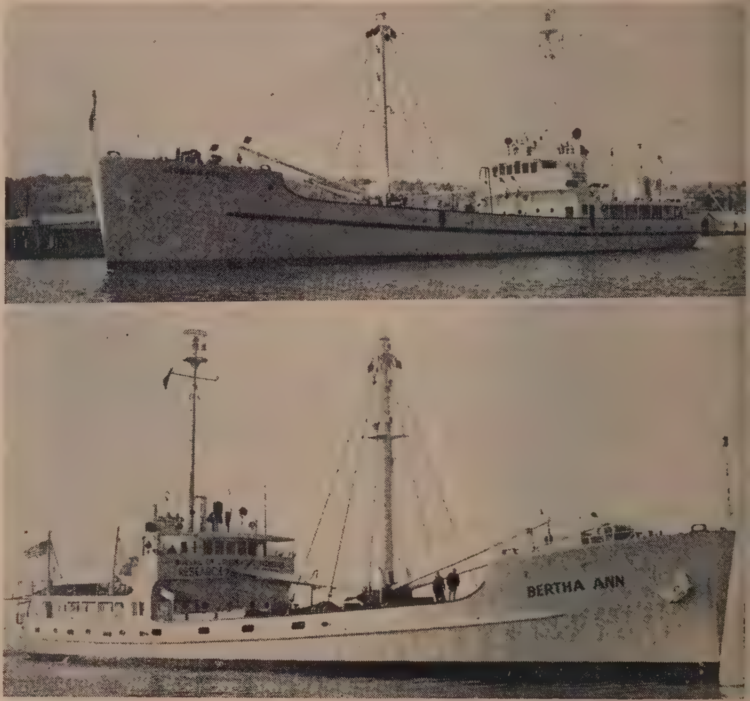
- The central North Pacific cruise, south of the Aleutians on 180° longitude, was interesting in that most of the Red salmon caught near the island chain were large, about 23" in length, but fish averaging 20" became dominant at the southern stations. The majority of the smaller, first-winter at sea Reds, about 11" long, were captured in the northern four stations along with the larger fish. Red salmon were caught at every central North Pacific station except the southernmost, with total catches decreasing from north to south. Total catches for the western series of stations in the North Pacific (sets 11-17) were 144 Reds, 62 Chums, 4 Pinks, 1 King, and 2 Silvers. The number of Chums approached that of the Reds in the catches of the southern five stations. Due to the decreasing catches and the zero catch of the *Kelez* at the same latitude, it is not believed that salmon would be found much farther to the south. In general, Red salmon catches south of Adak were at the same level as in the winter of 1962. Water temperatures here were considerably higher than in the Bering Sea and ranged from 38°F. in the north to 45°F. at the southernmost station.

● The cruise plan for the eastern North Pacific called for stations spaced 60 miles apart on 165°W., 155°W., and diagonally across the Gulf of Alaska to the Strait of Juan de Fuca. However, a combination of factors, primarily the almost continuously unfishable weather, forced a termination of the *Kelez'* cruise shortly after completion of the stations on 165°W.

Using the same gear make-up as the *Bertha Ann,* salmon catches at the eight successful *Kelez* stations on 165°W. were very low compared to catches of a year ago on 150°W. However, these catches were similar to those of the *Bertha Ann* farther to the west in 1963. Large Red salmon, 20 to 25" in length, dominated the five stations north of 49°N., but were absent from catches further south. Smaller, immature Reds, in their first-winter at sea, appeared in the next set at 47° 30'N. which was also the southern limit of Red salmon catches in the western Gulf. Small numbers of maturing Pink and Silver salmon were taken between 48° 30'N. and 46°N. No Chum or King salmon were taken in this area. The last set at 44° 30'N. was a blank haul, indicating the southern limit of salmon in February at this longitude to be about 45°N. Total catches for this cruise were 66 Reds, 13 Pinks, and 9 Silvers. Water temperatures were similar to those recorded by the *Bertha Ann* in the central North Pacific Ocean.

In all three fishing areas, a striking lack of aquatic life was observed in comparison with summer cruises. Whales, porpoises, and sea lions were totally absent and only three fur seals were seen in the Bering Sea and North Pacific. Herring gulls and, at the southernmost stations, albatross were the only birds commonly sighted. Also, incidental fish species such as Atka mackerel, pomfret, and Pacific mackerel, often taken in large numbers during the summer season, were not recorded; however, several large mackerel sharks were caught. In the Bering Sea large quantities of a cl
round, disc-like jelly fish, up to
in diameter, often fouled the n
These jelly fish were also present
in much smaller numbers in the
cific and Gulf.

Although weather conditions dur
the winter months are more sev
and the proportion of fishable d
is much lower than during the su
mer, these winter cruises have prov
that high seas salmon data can be c
lected throughout the year in all
the important sampling areas.



George B. Kelez and **Bertha Ann,** which conducted mid-winter gill-net researches for the U. S. Bureau of Commercial Fisheries west to 175° East Longitude and far north into Bering Sea.

High seas gillnetting aboard the **George B. Kelez** due south of Unimak Pas

(*Reprinted from Nature, Vol.* 199, *No.* 4890, *pp.* 250–251, *July* 20, 1963)

AN INDICATION OF UNDERWATER SOUND PRODUCTION BY SQUID

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IN recent years there have been many investigations of underwater sound production by marine animals and of the role of such sounds in animal behaviour. Most of this work has been focused on fish and mammals, and to a lesser extent on invertebrates.

The purpose of this communication is to present additional evidence of underwater sound production by marine squids. Several authors[1–3] have reported sound production by squids which were out of the water, but Nishimura[4] was the first to report on sounds produced underwater by squids. These sounds were recorded near trap nets in coastal waters off Atami City, Japan, and were called 'swimming noises' by Nishimura.

The underwater sounds reported here were tape-recorded aboard the U.S. Bureau of Commercial Fisheries research vessel *Hugh M. Smith* on November 3, 1958, at a night-light station (2130–2230 h) at position 2° 02′ N., 150° 07′ W. There was no wind, the sea surface was completely calm except for an occasional gentle swell, and the moon was not shining. A 200-W light was submerged 60 cm below the sea surface. A directional microphone mounted in a waterproof metal container was attached to the end of an 8-ft. aluminium handle. The microphone had a frequency response flat of approximately 300–5,000 c/s and an impedance of 25–50 ohms; other details are unknown. The observer manipulated the handle to train the microphone on squids in the water. The microphone housing was submerged about 1 m. Wiring from the microphone passed through a watertight connexion linking the aluminium handle and the microphone housing, up the hollow handle, and to a 'Magnecord *PT*6–*BN*' recorder operating at a tape speed of 7·5 in/sec. Comments by an observer were included on the same tape. The recorded sounds were graphically portrayed by a Kay 'Vibralyzer' sound spectrograph. Fig. 1 shows the entire frequency spectrum recorded. The recording shown in Fig. 2 was first passed through an Allison model 2*A* band-pass filter, which eliminated frequencies below 300

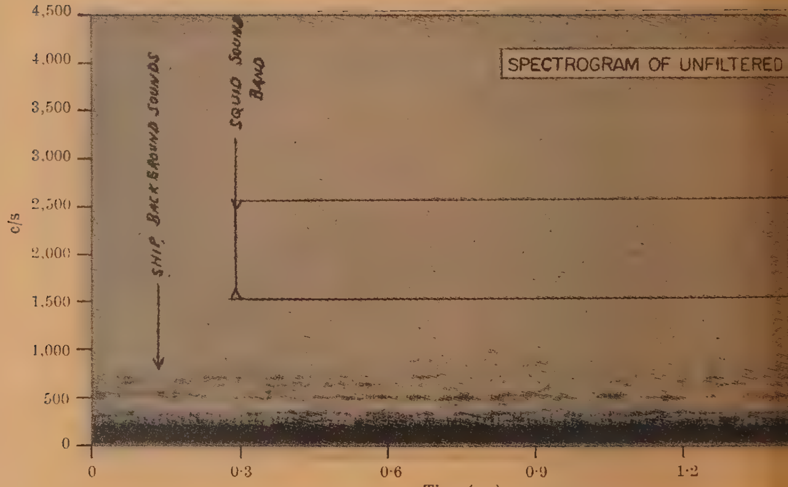

Fig. 1. Entire frequency spectrum recorded

and above 2,400 c/sec. No attempt was made to measure loudness of the sounds when originally recorded.

The squids, in groups of 10–20 individuals, swam rapidly in and out of the area illuminated by the night-light. Individual squids approached within 1 m of the microphone, and groups often passed beneath the microphone at a depth of 3–5 m. Squids of three species were captured by dipnet during the night-light station: one *Thysanoteuthis rhombus* Troschel—dorsal mantle-length 154 mm; one *Symplectoteuthis oualaniensis* (Lesson)—dorsal mantle-length 151 mm; and three *Onychoteuthis banksii* (Leach)—dorsal mantle-lengths 44 mm, 45 mm, and 65 mm. Squids observed near the microphone during sound recording were estimated to be about 150 mm in dorsal mantle length and were probably either *T. rhombus* or *S. oualaniensis*. Other animals, such as myctophids and flying fish, were also attracted to the night-light, but the recorded sounds were not noted when they were nearby.

The recorded sound burst shown in Fig. 2 was approximately 1·2 sec in duration and included 33 individual sound pulses. Time-intervals between pulses increased from 31 to 48 msec during the sound burst. The number of pulses ranged from 28 to 47 in six sound bursts analysed in this manner. To the human ear, sounds of the squids were a faint, rapid popping sound. Bartsch[3] also reported hearing popping sounds produced by squids, but by squids the speed of which had carried them clear of the water.

The recorded sound energy was concentrated above 1,500 c/s (Fig. 2), but since the darkness of the spectrogram reflects the 'Vibralyzer' dial settings, comparison of the intensities is only relative. The lower frequencies of the pulses reach 500 c/s; but here they are largely masked by what is probably machinery noise from the

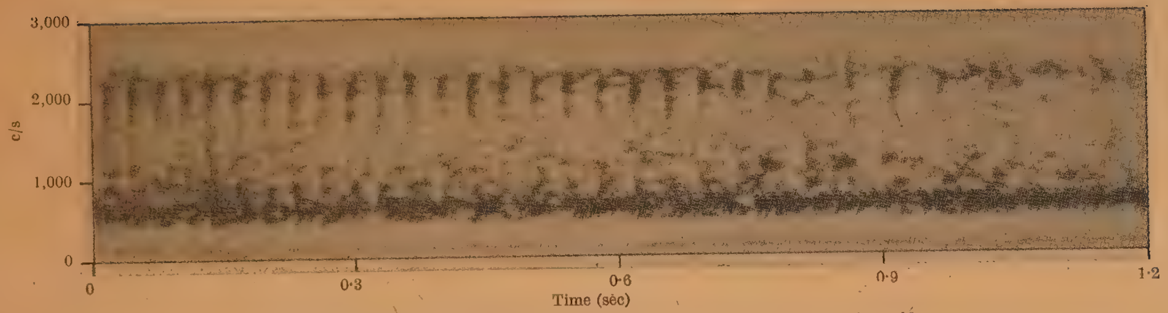

Fig. 2. Spectrogram of sound burst thought to have been made by oceanic squid

vessel, centred at 500 c/s. Sounds of squids recorded by Nishimura[4], analysed with a panoramic sound analyser, contained frequencies of 1,000–4,000 c/s. He recorded peak intensities at approximately 1,500 c/s, with the intensities dropping sharply above 1,500 c/s.

Voice comments recorded concurrently with the underwater sounds indicate that in the majority of cases squids were near the microphone when the sounds in question were recorded. For example, during one 30-min recording period, the observer noted the presence of squids near the microphone in 10 of 16 instances when sounds were recorded. The sounds were not always picked up even while squids were near the microphone. This suggests that sounds were produced sporadically by individuals, perhaps incidentally to abrupt changes in speed or to radical manœuvres.

The following hypothesis is offered to explain how these sounds are produced. The sounds may result from fluttering of the thin external lips of a squid's siphon while water is being ejected through the siphon from the mantle cavity. When the expulsion (or ejection) of water begins, pressure in the siphon would be greatest and the lips would flutter more rapidly than at the end of the ejection, when the water pressure in the siphon would be lower. This would account for the increasing interval between sound pulses in Fig. 1. The process is analogous to that which occurs when a small rubber balloon is filled with air and then released. As the air escapes, the neck and lips of the balloon flutter and a series of sound pulses are produced, decreasing in frequency as the air pressure within the balloon decreases.

The foregoing hypothesis was suggested because of the lengthening intervals between pulses towards the end of the sound burst. It is possible, however, that the bursts are some other swimming sound of the squids. In this regard, Figs. 1 and 2 are similar to a spectrogram recorded by Moulton (reported in ref. 5) of the swimming sounds of several million anchovies (*Anchoviella choerostoma*). This spectrogram also depicts short pulses of sound as vertical bars, but the bars are more irregularly spaced and show frequencies approaching 5,000 c/s.

The hard beaks of the squids should also be mentioned as possible sound producers. On one occasion while squids were nearby, a faint snap was heard instead of the usual popping sound.

We thank Dr. William N. Tavolga for advice.

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Printed in Great Britain by Fisher, Knight & Co., Ltd., St. Albans.

APPENDIX I. A STANDARD TERMINOLOGY AND NOTATION FOR OTOLITH AGE READERS

by Albert C. Jensen
Bureau of Commercial Fisheries, Biological Laboratory, Woods Hole, Mass.

Results of the cod otolith exchange program (Anon., 1959), and the analysis of a questionnaire (Keir, 1960) distributed to biologists engaged in age determination of fishes, indicated some important disagreements between different workers, particularly in the terminology used to report their findings. Because of the fundamental importance of age data to the work of ICNAF the Standing Committee on Research and Statistics recommended at the 1960 Annual Meeting (Anon., 1960) that a working party on ageing techniques be set up to resolve these disagreements, and to draw up a uniform set of terms and symbols.

Dir. Gunnar Rollefsen was appointed Convenor of the working party that met in Bergen 19-24 November, 1962. During the meeting the working party discussed a preliminary listing of terms, definitions, and abbreviations prepared by the author. The present paper represents the consensus of the members of the working party and is prepared for use in the laboratories of ICNAF members, in otolith exchange reports, and in the preparation of papers dealing with otolith studies.

The terms have been kept as simple as possible. Preference has been given to terms that have precedence in the literature or have a valid historical basis. Quite often the oldest term is the best term.

Terms that deal with validity of methods (e.g., year-marks), and terms for which the dictionary definition has been replaced by a common usage definition (e.g., annulus) are not considered here. The proposed terms are intended to be descriptive and of a restricted nature. Also they are terms that will have a similar meaning when translated from English, the official language of ICNAF, into the various languages of the ICNAF members.

Otolith Marks

Term	Synonyms	Definition
Zones	Annuli, rings, year marks, bands, winter rings, summer rings, growth rings	Bands of concentric hyaline or opaque material seen in otoliths and counted for age determination.
Check	Check mark, check ring, false ring, secondary ring, secondary zone, split	Hyaline matter not counted in age determination. Checks are sometimes indistinct, discontinuous or, in the judgement of the reader, do not meet the criteria established for identification as a year mark.

Reprint from International Commission for the Northwest Atlantic Fisheries, Redbook, Part III, December 1963.

Term	Synonyms	Definition
Nucleus	Focus, center, origin, kernel	The central area of the otolith bounded by the first check or zone. (In most laboratories the center of the otolith is not fully understood, thus many biologists have not yet developed a firm definition for this term.)
Opaque edge	Summer edge, fast-growth edge, dense edge	The otolith periphery composed primarily of opaque material.
Hyaline edge	Winter edge, slow-growth edge, translucent edge	The otolith periphery composed primarily of hyaline material.
Spawning zones	Spawning marks, spawning rings	Hyaline and opaque zones formed in the otolith from the onset of sexual maturity. In general both hyaline and opaque zones of spawners are uniform in size and form, and the opaque zones are distinctively narrower than those formed during the immature period of the fish's life. The hyaline spawning zones are clear and usually free of opaque material; in many species (e.g. cod) they are frequently broader than the subsquent opaque zones.

Readability of Otoliths

A system of number notations is proposed to grade the readability of the otoliths. Such notations will also serve as a guide to the reliability of the ages determine for each otolith. The numbers will permit use of these notations in IBM and similar machine systems.

Notation and term	Definition
0 - - Good	The zones are plainly visible with generally good definition between hyaline and opaque zones. Any check readily identifiable as such. The reader has a good decree of confidence in resulting age determination.
1 - - Fair	The zones are visible but not well defined. There are many checks present. The reader has fair degree of confidence in resulting age determination. In many otoliths the zones ma form distinct patterns that make reliable age determinations feasible.

Term	Definition
2 - - Poor	The zones are vaguely marked. Otoliths with zones so poorly defined as to be undecipherable, or where the age is merely estimated, are placed in this category.

Abbreviations and Symbols

It is desirable to keep abbreviations and symbols to a minimum and as simple as possible. Any lengthy comments on the appearance of the otolith and its markings, or on the degree of confidence of the determined age, are best made in an appropriate remarks' column on the form used to record the results of the otolith reading.

Asterisks, plus and minus signs, or other addenda to the age notation, serve only to clutter the data. When comparing the results of duplicate otolith readings, the reader's first concern is, "Do the ages agree?". After this, the question may be asked, "Why did the duplicate readings agree (or disagree)?" Symbols and remarks will serve to answer the second question, but they should not clutter the sheet such that, after the otolith has been studied and an age assigned, the data sheet must be studied to find the notation of age.

Type of edge growth

Determining the type of growth (hyaline or opaque) seen at the edge of the otolith can, at times, be difficult and sometimes depends upon the subjective judgement of the reader. Final determination of the type of edge growth is influenced by the manner in which the otolith is cut or broken for reading and usually the beginning of the new growth is best seen at the narrow tip of the long axis of the otolith. These factors must be taken into consideration by the reader when he records his observation of the type of edge growth. Since the type of edge growth is used to translate age determinations from zone counts, recognition of the edge type is essential to the otolith reading process. To help in this recording, the following abbreviations are proposed:

Hn - narrow hyaline zone at edge (1)
Hw - wide hyaline zone at edge (2)
On - narrow opaque zone at edge (3)
Ow - wide opaque zone at edge (4)

For card punch systems (IBM, Keysort, etc.), the numerical notation may be substituted for the abbreviation, but care should be exercised to avoid confusing the edge code number with the age or zone-count number.

Checks

$C_{3,4}$ - check in third and fourth opaque zone

Spawning zones

12(4s) - total of 12 zones of type counted, 4 of which are spawning zones

Age notation

9 - clearly, nine completed zones of the type counted
9(10) - probably nine, possibly ten completed zones
(8)9(10) - probably nine but possibly eight or ten completed zones
12(?) - best estimate of count from ambiguously marked otolith

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EXTRAIT

[redacted]

ICNAF Spec Pub No 4
1963
North Atlantic Fish
Marking Symposium

[redacted]

30.

Further Field Experiments with Tags for Haddock

By

ALBERT C. JENSEN*

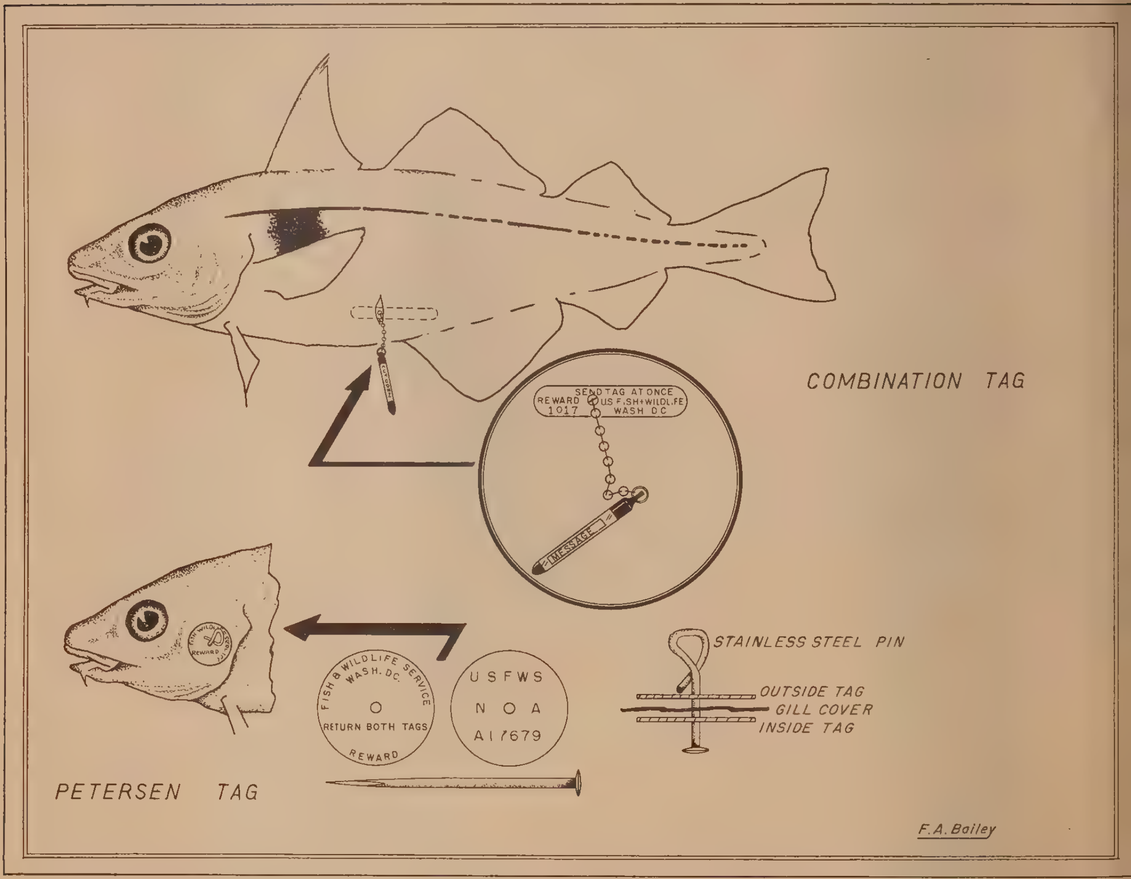
COMBINATION TAG
SEND TAG AT ONCE
REWARD
1017
US F.SH+WILDL.FE
WASH D.C.
MESSAGE
STAINLESS STEEL PIN
OUTSIDE TAG
GILL COVER
INSIDE TAG
FISH & WILDLIFE SERVICE
WASH. D.C.
RETURN BOTH TAGS
REWARD
USFWS
NOA
A1 7679
PETERSEN TAG
F.A. Bailey

Figure 1. The Petersen tag and the combination tag used in haddock research.

Introduction

In the period from 1923 to 1932, nearly 11,000 tagged haddock (*Melanogrammus aeglefinus*) were released in the Gulf of Maine-Nantucket Shoals area as part of a migration study (Schroeder, 1942). The results of these experiments were extremely discouraging since only about 2 percent of the marked fish were returned, compared with about 12 percent returns for cod captured in the same manner, on the same grounds, and tagged with the same tag (Schroeder, 1930).

Fish for tagging were caught with hand lines and tagged with Monel strap tags (Rounsefell and Kask, 1945) attached to the dorsal part of the caudal fin. Schroeder (1942) concluded that the poor r of return resulted from tags being shed, "...perha as many as 70 to 80 percent," within the first 3 6 months after tagging.

Subsequent haddock tagging, conducted by t Bureau of Commercial Fisheries Biological Labo tory from 1930 to 1932, and reported by Rounse (1942), also yielded poor returns. In these experime the haddock were caught by otter trawls; 440 w tagged with bachelor button tags and 82 with bo cavity tags (Rounsefell and Kask, 1945). None w ned. In a later experiment, 259 haddock were d with bachelor button tags and 101 with body y tags. One bachelor button tag was returned. e fish were captured with line trawls fished large commercial vessels. It was presumed the poor returns were due to fish mortality caused ne method of capture and subsequent handling. efore, in 1933, tagging was conducted from a l line trawler near the coast of Maine. In this riment 332 haddock were marked with bachelor on tags and 117 with body cavity tags. Rounsefell 2) reports 26 returns (5.8 percent) but does not cate a breakdown by tag type.

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* U. S. Department of the Interior, Fish and Wildlife Serv Bureau of Commercial Fisheries Biological Laboratory, Wo Hole, Massachusetts.

1938, 1939 and 1940 the experiments were resumed unsefell, 1942). Haddock were again tagged a line trawler, during the first part of June in rs ranging from 15 to 30 fathoms deep off Mount rt Island, Maine. In all, 2,073 fish were tagged by June 1941, 321 (15.5 percent) were recaptured.

ounsefell used three types of tags in different binations each year; the bachelor button tag he operculum (1938—1939), the internal anchor 1938—1940), and the Petersen tag on the oper- m (1938—1939—1940). The tags are illustrated described by Rounsefell and Kask (1945). To inate any variables introduced by using different at different times, he rotated the tags so that n three types were being tested, every third was marked with the same type. On the basis of experiment, he concluded that the Petersen gave the highest initial return but poorer returns . The bachelor button tag yielded more long- recaptures than the Petersen tag, but presented hanical problems in its method of attachment. internal anchor tag remained attached longer the Petersen tag and possibly longer than the elor button tag, but because the dangler and n were too easily lost the tag needed improvement re further use.

ncouraged by Rounsefell's success, we began a -scale haddock tagging program in 1953 and in the offing of Chatham, Massachusetts, aboard -foot line trawler. Nearly 2,000 haddock were ed either with Petersen tags on the operculum vith modified internal anchor ("combination") (Fig. 1). Additional large-scale haddock tagging conducted, with otter-trawl-caught fish, from *Albatross III*, beginning in 1957 using Petersen and plastic "spaghetti" tags (Wilson, 1953).

nis report discusses the relative merits of the tags in the Chatham and *Albatross III* tagging studies. studies were conducted as part of the haddock definition program, and as further field tests e Petersen tags, combination tags, and spaghetti Additional information was gained about the growth of haddock and the problems of tagging from otter trawlers.

In previous experiments, tagging haddock from otter trawlers had been notably unsuccessful. Such tagging by W. C. Herrington (and reported by Rounsefell, 1942) yielded no returns from 522 tagged fish. In 1950, more than 1,800 haddock were taken in an otter trawl by the *Albatross III* and tagged with Petersen tags. Less than 1 percent of these fish were recovered (Fish and Wildlife Service unpublished records).

Tagging Methods

Line trawl tagging. — Beginning in the autumn of 1953 and continuing through the summer of 1954, periodic trips were made aboard a line trawler out of Chatham, Massachusetts, to tag haddock. The vessel fished with commercial gear, in its usual manner, and we selected the liveliest-looking fish from those caught during the normal day's operation. The tagging area was a regularly-fished ground, 17 miles east-southeast of Pollock Rip light vessel in depths between 15 and 30 fathoms.

The fish were tagged with Petersen tags or combination tags that consisted of an internal anchor connected to a Lea hydrostatic capsule with a short length of Monel chain (Wise, 1958). The internal anchor was inserted through an incision in the flank of the fish. The Petersen tags were attached to the operculum with nickel pins in the manner described by Rounsefell (1942), in which the pin is threaded through the center of one disc and then pushed through the operculum from the inside. The second disc is then threaded on the projecting point of the pin. The surplus part of the pin is cut off and the remainder twisted into a loop and bent over with longnosed pliers. The fish were measured and then released.

The Petersen tags and combination tags were rotated in use except that two combination tags were used for each Petersen tag used. A total of 1,870 haddock were tagged; 1,253 with combination tags and 617 with Petersen tags.

Otter trawl tagging. — In March and April 1957, haddock were tagged on Georges and Browns Banks aboard the research vessel *Albatross III.* A Yankee 41 otter trawl with a fine-mesh cod end cover was towed for 20 to 60 minutes in depths from 24 to 56 fathoms. At the end of the tow, the net was hauled back and the contents of the cover emptied into circular wooden tanks supplied with running sea water. The cod end, which usually contained large numbers of anglers, skates, and miscellaneous species, was emptied on deck. The haddock that had escaped through the meshes of the cod end into the cover were usually in good condition, with little or no indication of abrasion or other injury. Presumably this was because they were not in contact with the rough fishes during the haulback. Sluggish haddock were removed from the tank. The lively ones were dipnetted individually and handed to the tagger who attached the tag, measured the fish, and immediately released it over the side of the vessel.

On Georges Bank, 297 fish were tagged with Petersen tags on the operculum, 179 with Petersen tags attached dorsally, and 221 with spaghetti tags attached dorsally. On Browns Bank, 640 haddock were tagged with Petersen tags on the operculum, 399 with Petersen tags attached dorsally, and 272 with spaghetti tags attached dorsally.

The Petersen tags on the operculum were attached in the same manner as for the line trawl tagging described previously, except that stainless steel pins were used instead of nickel pins. An aquarium study with tagged haddock (Jensen, 1958) had shown that the stainless steel pins were more resistant to sea water corrosion than the nickel pins. The dorsal Petersen tags were attached with stainless steel wire through the dorsum, immediately anterior to the first dorsal fin.

The spaghetti tag is a 350-mm length of 2.5-mm (outside diameter) yellow Vinyl plastic tubing with a serial number and return address imprinted with waterproof ink. The tubing is drawn through
dorsal muscles, between the first and second do
fins, and the free ends of the tube tied in a sin
overhand knot.

The Petersen tags and spaghetti tags were
alternately on the Georges Bank haddock. On Bro
Bank, two haddock were tagged with Petersen tags
each one tagged with the spaghetti type. Howe
the principle of alternation of tags was followed
that every third fish was tagged with the spaghetti

Results

Line trawl. — Of the total of 1,870 haddock tag
off Chatham, 221 (11.8 percent) were return
as follows: 63 Petersen tags (10.2 percent) and
combination tags (12.4 percent) (Table 1).
shown in Figure 2 and Table 1, the Petersen tags g
a high initial return and then began to diminish a
about 30 weeks. Fewer fish with combination t
were returned at first but the percentage of retu
increased rapidly. At 60 weeks both tags yiel
about the same percentage of returns. The ini
fish mortality, from the effect of tagging, is proba
higher with the combination tag but actual loss
tags is probably greater with the Petersen

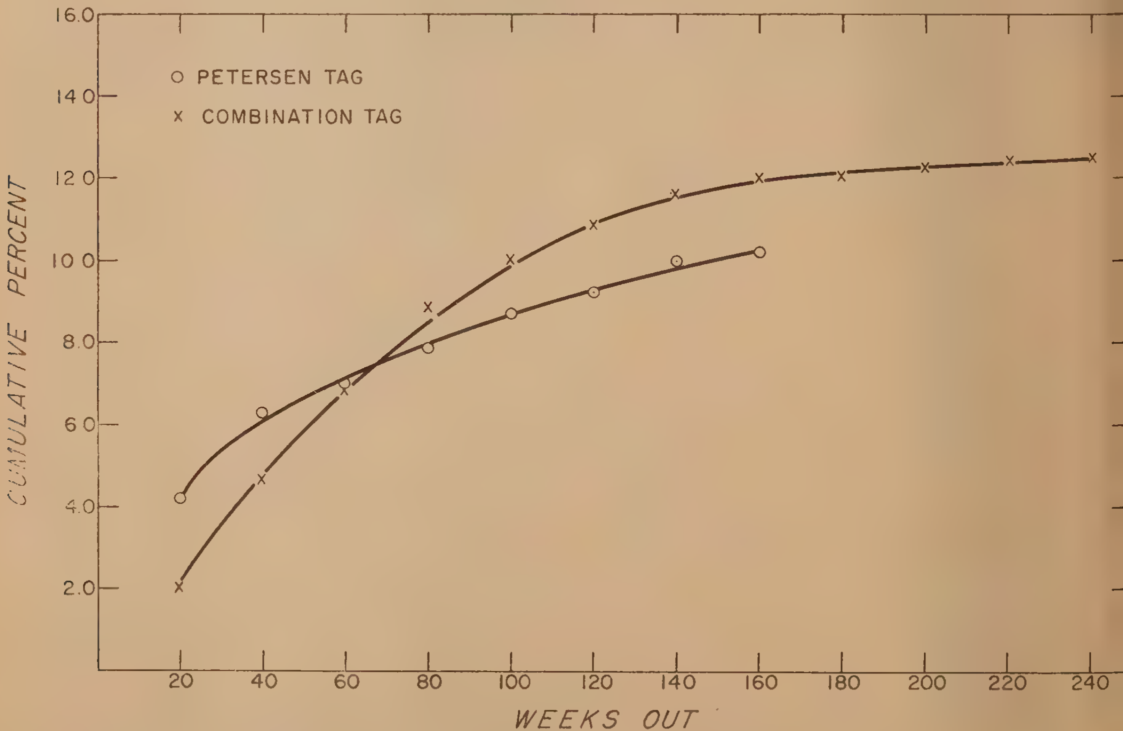


Figure 2. Graph comparing rate of return of Petersen tags and combination tags, Chatham, 1953—1954.

rium studies (Jensen, 1958) have shown that the sen tag on haddock may be grown over and not or may cause an opercular ulceration and be

t the 60-week level, both tags still yielded about same percentage of returns; no Petersen tags were rned after 160 weeks. The combination tags, however, continued to be returned beyond 160 weeks, and one fish (possibly others not captured) retained the tag for nearly 5 years. The chain was worn thin on some of the combination tags out for long periods, and the nickel pins with Petersen tags showed some corrosion. In many cases, finders noted that operculum tissue under the Petersen tags was raw and eroded.

Although we have no measure of the loss, undoubtedly tags of both types were lost even though the fish were later recaptured. This was demonstrated when the skipper of the tagging boat later recaptured a haddock that had been tagged with a combination tag. The chain had broken close to the internal anchor leaving no external evidence of the tag. While gutting the fish, the skipper noticed a lump on the liver that proved to be the internal anchor portion overgrown with liver tissue. It might never have been seen had the fish been gutted by a less observant person.

Table 1

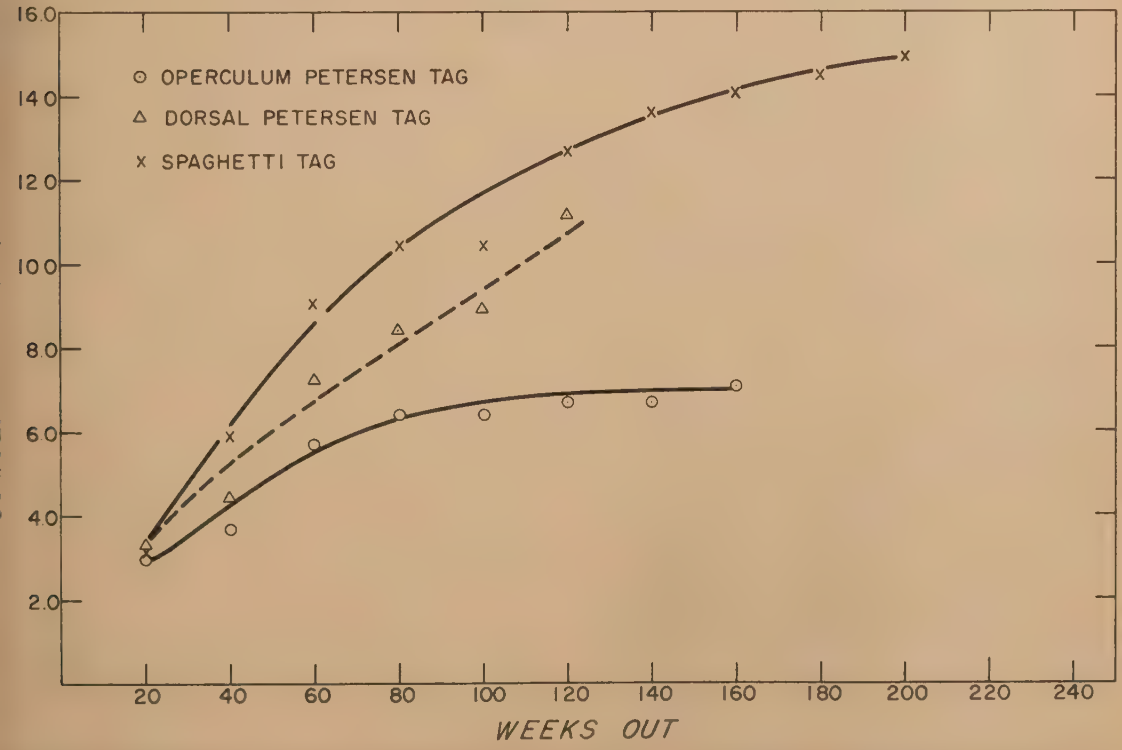
ulative number and percentage returns, by 20-week vals, of Petersen tags and combination tags used on haddock, Chatham, 1953—1954

(Cumulative numbers in parentheses)

at ty ks)	Petersen tags (No.)	 (%)	Combination tags* (No.)	 (%)
-20	26 (26)	4.2	26 (26)	2.1
-40	13 (39)	6.3	33 (59)	4.7
-60	4 (43)	7.0	27 (86)	6.9
-80	6 (49)	7.9	25 (111)	8.9
-100	5 (54)	8.7	14 (125)	10.0
-120	3 (57)	9.2	10 (135)	10.8
-140	5 (62)	10.0	10 (145)	11.6
-160	1 (63)	10.2	5 (150)	12.0
-180			1 (151)	12.0
-200			3 (154)	12.3
-220			1 (155)	12.4
-240			1 (156)	12.4

Two tags with recovery date lacking, not included.

Otter trawl. — The results of the tagging experiments aboard the *Albatross III* are reported separately for Georges and Browns Banks, for several reasons. The area on Georges in which we tagged haddock is fished year-round by United States vessels, whereas Browns Bank is fished only in the first few months of the year and is little fished by Canadian vessels. Thus, there is a greater likelihood for tagged fish



re 3. Graph comparing rate of return of operculum Petersen tags, dorsal Petersen tags, and spaghetti tags, Georges Bank, 1957.

Table 2

Cumulative number and percentage returns, by 20-week intervals, of Petersen tags on the operculum and on the dorsum, and spaghetti tags on the dorsum, Georges Bank, 1957

(Cumulative numbers in parentheses)

Time at liberty	Petersen tags				Spaghetti tags	
	Operculum		Dorsum			
(weeks)	(No.)	(%)	(No.)	(%)	(No.)	(%)
0—20	9 (9)	3.0	6 (6)	3.3	7 (7)	3.2
21—40	2 (11)	3.7	2 (8)	4.5	6 (13)	5.9
41—60	6 (17)	5.7	5 (13)	7.3	7 (20)	9.0
61—80	2 (19)	6.4	2 (15)	8.4	3 (23)	10.4
81—100	0 (19)	6.4	1 (16)	8.9	0 (23)	10.4
101—120	1 (20)	6.7	4 (20)	11.2	5 (28)	12.7
121—140	0 (20)	6.7			2 (30)	13.8
141—160	1 (21)	7.1			1 (31)	14.0
161—180					1 (32)	14.5
181—200					1 (33)	14.9

to be recaptured on Georges than there is on Browns. Scale studies have shown that Browns Bank haddock grow at a slower rate than Georges Bank haddock (Wise, 1957) and the two groups do not mingle to any great extent.

Tag returns from Georges Bank include 21 (7.1 percent) Petersen tags on the operculum, 20 (11.2 percent) Petersen tags on the dorsum, and 33 (14.9 percent) spaghetti tags (Table 2). The pattern c
turns has been somewhat similar to that of the (
ham tagging study. The three kinds of tags yie
about the same percentage of returns through
first 20 weeks, but after 60 weeks the return
for operculum Petersen tags began to decline
contrast, the returns of dorsal Petersen tags
spaghetti tags continued to rise (Fig. 3).

Table 3

**Cumulative number and percentage returns, by 20-
intervals, of operculum Petersen tags, dorsal Petersen
and spaghetti tags on the dorsum, Browns Bank,**

(Cumulative numbers in parentheses)

Time at liberty	Petersen tags				Spaghett
	Operculum		Dorsum		
(weeks)	(No.)	(%)	(No.)	(%)	(No.)
0—20	9 (9)	1.4	2 (2)	0.5	8 (8)
21—40	4 (13)	2.0	0 (2)	0.5	6 (14)
41—60	13 (26)	4.1	4 (6)	1.5	10 (24)
61—80	3 (29)	4.5	0 (6)	1.5	2 (26)
81—100	0 (29)	4.5	2 (8)	2.0	1 (27)
101—120	1 (30)	4.7	2 (10)	2.5	5 (32)
121—140	0 (30)	4.7			1 (33)
141—160	3 (33)	5.2			2 (35)
161—180	1 (34)	5.3			
181—200	0 (34)	5.3			
201—220	1 (35)	5.5			

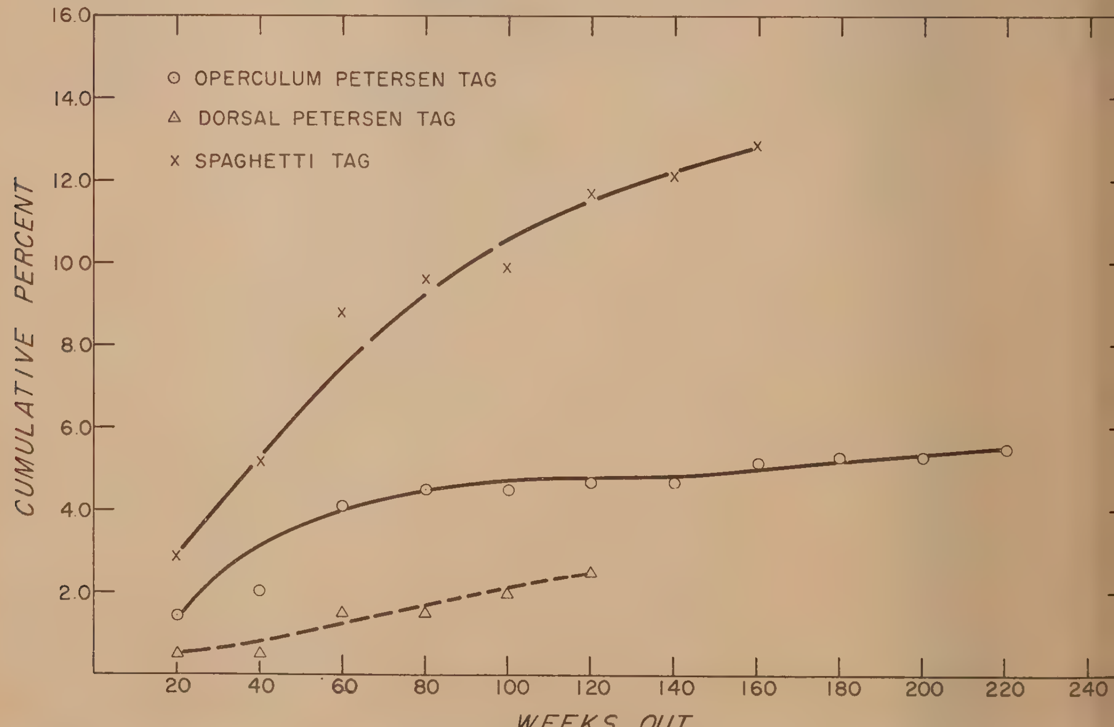


Figure 4. Graph comparing rate of return of operculum Petersen tags, dorsal Petersen tags, and spaghetti tags, Browns Bank,

the haddock tagging on Browns Bank, despite greater number used, the Petersen tags yielded a of only 41 returns — 31 (7.5 percent) on the ulum and 10 (2.5 percent) on the dorsum — pared with the spaghetti tag that yielded 35 rns (12.9 percent) (Table 3). The pattern of rns has been quite different. The rate for Petersen operculum and dorsal) was low at the beginning leveled off at a low rate after 60 weeks. The hetti tags were returned at a good rate, though were returned after 160 weeks (Fig. 4).

wth of Tagged Fish

agging experiments offer one of the best methods obtaining empirical growth data for fish, since fish are measured when tagged and again n recaptured, and the time interval is precisely wn. When tagged fish are recaptured, however, finder often neglects to include an adequate gth measurement, or reports the size of the fish 1½ pounds," or "19½ inches long."

The most reliable length measurements we have recaptured fish are those made by our technicians the several ports. Because of the small sample ained, however, the data do not lend themves to sophisticated statistical analysis and can e only the grossest indication of growth. Instead, have simply determined a weighted mean weekly wth for fish tagged with each kind of tag.

Line trawl. — Haddock tagged with Petersen s grew at a faster rate than those tagged with mbination tags. It is interesting to note that the fish tagged with Petersen tags in November 1953 grew an average of 1.4 mm per week over periods that ranged from 10 to 123 weeks, and the 10 fish ged in April 1954 grew an average of 0.99 mm week over periods that ranged from 14 to 105 eks. The 7 fish tagged in August 1954 grew an erage of 1.2 mm per week over periods of from to 122 weeks (Table 4). It seems reasonable to mbine the data and state an average growth of 1.1 mm per week for the fish tagged with Petersen gs.

For the returns from the November 1953 tagging, average length growth per week (for periods from 10 to 141 weeks) was 0.9 mm for the 5 fish tagged with the combination tag; for the April 1954 tagging was 0.8 mm for the 29 fish, for periods from 15 to 108 weeks. The 7 fish returned from the August 954 tagging grew an average of 0.6 mm per week over periods of from 31 to 97 weeks (Table 5). Again mbining these data, we may state 0.7 mm per eek as an average growth for the haddock tagged ith the combination tag.

Table 4

Growth of haddock tagged with Petersen tags on the operculum, Chatham, 1953—1954

Date Tagged	Date Recap.	Time at liberty weeks	Length Tagged mm	Length Recap. mm	Growth mm	Growth per week mm
Nov 1953	Feb 1954	10	510	537	27	2.7
	Apr 1955	74	480	577	97	1.3
	May 1955	78	540	640	100	1.3
	July 1955	84	570	654	84	1.0
	Mar 1956	123	510	625	115	0.9
					x̄ =	1.4
Dec 1953	Apr 1955	120	480	545	65	0.5
Apr 1954	July 1954	14	537	555	18	1.3
	Aug 1954	14	438	445	7	0.5
	Feb 1955	44	578	632	54	1.2
	Mar 1955	48	506	564	58	1.2
	July 1955	63	529	562	33	0.5
	Oct 1955	77	486	544	58	0.7
	Oct 1955	78	539	584	45	0.6
	Dec 1955	85	348	521	173	2.0
	Feb 1956	94	507	620	113	1.2
	May 1956	105	541	565	24	0.2
					x̄ =	0.99
July 1954	Sept 1955	62	579	628	49	0.8
Aug 1954	Sept 1954	8	418	420	2	0.2
	Dec 1954	16	443	486	43	2.7
	Jan 1955	23	430	449	19	0.8
	Mar 1955	31	565	571	6	0.2
	Mar 1955	32	518	551	33	1.0
	Sept 1955	56	528	700	172	3.1
	Dec 1955	122	530	572	42	0.3
					x̄ =	1.2
					Grand average =	1.1

Otter trawl — As was the case with the line trawl tagging experiments, the number of reliable length measurements obtained at the time of return from the otter trawl tagging experiments is small and the data are not suitable for statistical analysis. However, by again examining the average growth per week, we are afforded a rough approximation of the differences in growth between the fish tagged with Petersen tags and those tagged with spaghetti.

On Georges Bank the haddock tagged with spaghetti tags grew at a much faster rate than those with Petersen tags (Table 6). The 9 haddock tagged on the operculum with Petersen tags grew an average of 0.5 mm per week over periods of from 6 to 80 weeks at large. The 21 haddock tagged with spaghetti tags grew an average of 0.8 mm per week over periods of from 6 to 182 weeks. The 8 fish tagged dorsally with Petersen tags grew an average of 0.5 mm per week over a period of from 13 to 107 weeks.

The growth of tagged Browns Bank haddock (Table 7) was less than that for the tagged Georges Bank haddock, but this is to be expected since scale readings show that Browns Bank fish grow at a slower

Table 5

Growth of haddock tagged with combination tags, Chatham, 1953—1954

Date Tagged	Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Growth per week (mm)
Nov 1953	Feb 1954	13	560	575	15	1.2
	Oct 1954	47	520	568	48	1.0
	Jan 1955	62	500	543	43	0.7
	Oct 1955	100	480	541	61	0.6
	Aug 1956	141	540	657	117	0.8
					x̄ =	0.9
Dec 1953	Sept 1955	88	530	635	105	1.2
	Apr 1956	120	540	595	55	0.5
	Apr 1958	223	520	680	160	0.7
					x̄ =	0.8
Apr 1954	Aug 1954	15	577	580	3	0.2
	Aug 1954	16	668	678	10	0.6
	Oct 1954	25	566	578	12	0.5
	Oct 1954	26	563	574	11	0.4
	Oct 1954	26	464	505	41	1.6
	Dec 1954	33	517	548	31	0.9
	Mar 1955	48	655	668	13	0.3
	Apr 1955	50	529	584	55	1.1
	May 1955	55	600	646	46	0.8
	June 1955	60	569	635	66	1.1
	June 1955	61	567	635	68	1.1
	July 1955	63	520	591	71	1.1
	July 1955	64	464	542	78	1.2
	July 1955	64	552	609	57	0.9
	July 1955	65	505	572	67	1.0
	July 1955	66	515	539	24	0.4
	Aug 1955	70	474	533	59	0.8
	Sept 1955	73	510	584	74	1.0
	Sept 1955	73	488	562	74	1.0
	Nov 1955	81	635	660	25	0.3
	Mar 1956	97	705	750	45	0.5
	Apr 1956	103	564	667	103	1.0
	May 1956	105	603	686	83	0.8
	May 1956	109	545	584	39	0.4
	June 1956	111	583	619	36	0.3
	Oct 1956	130	505	635	130	1.0
	Nov 1956	134	551	680	129	1.0
	Dec 1956	138	529	623	94	0.7
	Feb 1957	150	551	639	88	0.6
					x̄ =	0.8
Aug 1954	Mar 1955	31	631	639	8	0.3
	Mar 1955	32	478	483	5	0.2
	June 1955	46	566	580	14	0.3
	Sept 1955	60	541	584	43	0.7
	Oct 1955	64	562	591	29	0.4
	Jan 1956	74	688	720	32	0.4
	June 1956	97	494	647	153	1.6
					x̄ =	0.6
					Grand average =	0.7

rate. The 10 fish tagged on the operculum with Petersen tags and at large for from 35 to 210 weeks grew an average of 0.4 mm per week. The growth of the 10 spaghetti-tagged fish, at large for from 37 to 160 weeks, grew an average of 0.4 mm per week. The 3 fish tagged dorsally with Petersen tags grew an average of 0.5 mm per week ov period of 52 to 105 weeks.

It seems certain the physical presence of the inhibited the normal growth rate of the ta haddock. Untagged haddock, with about the size composition as the tagged haddock reporte this paper, grow at the following rates: Ge Bank, 1.0 mm per week (Jensen and Wise, 19 Browns Bank, 0.6 mm per week (Wise, 1957).

Table 6

Growth of haddock tagged on Georges Bank,

Date Tagged	Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Gr per (r
			Petersen tags on the operculum			
Mar 1957	May 1957	6	584	590	6	
	Sept 1957	23	484	501	17	
	Sept 1957	24	482	490	8	
	Mar 1958	49	585	597	12	
	Mar 1958	52	423	470	47	
	May 1958	58	477	500	23	
	May 1958	58	579	590	11	
	June 1958	63	497	515	18	
	Oct 1958	80	517	569	52	
					x̄ =	
			Petersen tags on the dorsum			
Mar 1957	June 1957	13	434	440	6	
	Mar 1958	51	552	558	6	
	Mar 1958	52	583	588	5	
	May 1958	60	584	616	32	
	May 1958	61	451	484	33	
	July 1958	69	501	565	64	
	Mar 1959	105	658	760	102	
	Apr 1959	107	483	526	43	
					x̄ =	
			Spaghetti tags			
Mar 1957	May 1957	6	608	610	2	
	May 1957	7	462	473	11	
	May 1957	8	565	577	12	
	June 1957	11	588	619	31	
	Aug 1957	22	467	475	8	
	Oct 1957	31	532	564	32	
	Feb 1958	45	572	590	18	
	Apr 1958	56	480	554	74	
	Apr 1958	57	568	582	14	
	May 1958	61	540	577	37	
	May 1958	62	454	495	41	
	June 1958	62	342	426	84	
	Feb 1959	102	485	512	27	
	Mar 1959	102	548	567	19	
	Apr 1959	109	483	542	59	
	Apr 1959	109	493	603	110	
	Aug 1959	126	474	587	113	
	Nov 1959	137	475	532	57	
	Feb 1960	151	532	585	53	
	May 1960	162	556	640	84	
	Sept 1960	182	355	570	215	
					x̄ =	

Table 7

th of haddock tagged on Browns Bank, 1957

Date ged	Recap.	Time at liberty (weeks)	Length Tagged (mm)	Length Recap. (mm)	Growth (mm)	Growth per week (mm)
		Petersen tags on the operculum				
1957	Dec 1957	35	548	559	11	0.3
	Mar 1958	53	549	570	21	0.4
	Apr 1958	55	482	490	8	0.1
	Apr 1958	56	512	544	32	0.6
	June 1958	63	497	518	21	0.3
	July 1958	69	486	527	41	0.6
	Mar 1960	152	472	575	103	0.7
	Apr 1960	160	512	551	39	0.2
	June 1960	166	472	550	78	0.5
	Apr 1961	210	472	511	39	0.2
						$\bar{x}$ = 0.4
		Petersen tags on the dorsum				
: 1957	Mar 1958	52	550	575	25	0.5
	Feb 1959	98	524	610	86	0.9
	Apr 1959	105	592	609	17	0.2
						$\bar{x}$ = 0.5
		Spaghetti tags				
r 1957	Dec 1957	37	514	539	25	0.7
	Feb 1958	48	545	578	33	0.7
	Mar 1958	52	548	587	39	0.7
	Mar 1958	53	535	545	10	0.2
	Jan 1959	96	570	580	10	0.1
	Mar 1959	105	471	500	29	0.3
	Apr 1959	106	513	544	31	0.3
	Aug 1959	126	576	623	47	0.4
	Feb 1960	151	458	506	48	0.3
	Apr 1960	160	551	576	25	0.2
						$\bar{x}$ = 0.4

Thus, for Georges Bank haddock, fish marked th Petersen tags (both methods of attachment) ew at 50 percent of the rate for untagged fish, ile the fish marked with spaghetti tags grew at percent of the rate for untagged fish. For the Browns nk haddock, the fish marked with dorsal Petersen gs grew at 83 percent of the rate for untagged h, while the fish marked with operculum Petersen gs, or with spaghetti tags, grew at 67 percent of rate for untagged fish.

Unfortunately, the data for untagged fish are not obtainable to make a similar comparison for the Chatham experiment.

Factors Affecting Tag Returns

Tag visibility. — Much of the value of a tag recovery is lost if the tag is seen at such a late stage in the marketing chain that the fish cannot be traced back to the area and date of capture with a reasonable degree of certainty. In Table 8, I have listed the numbers and percentages of tagged fish and the places in which the tags were discovered.

In the Chatham tagging, the Petersen tags were discovered on the vessel 68 percent of the time, the combination tags were discovered thus 60 percent of the time. The small difference in percentage indicates that both tags were equally visible to the fishermen. The kind of fishery involved may have some bearing on the place of discovery, since nearly $^{1}/_{4}$ (23 percent) of all the returned Chatham tags were found aboard line trawlers. In this type of fishery the fish receive more or less individual attention, in contrast to the obscurity of individual fishes aboard an otter trawler when the cod end load is dumped into the checkers.

It is surprising to note that so many tags (nearly 10 percent of Petersen tags and 19 percent of combination tags) passed through numerous hands to be discovered in the retail market; and we received 3 tags from housewives who discovered them while cleaning fish for supper! Undoubtedly, the sheer mass of fish aboard ship and ashore, the need of the handler to hurry along with his tasks, and the mental attitude or preoccupation of the handler, all contribute to tags passing unnoticed.

It was our hope that the use of spaghetti tags in the offshore tagging would result in a higher recovery rate aboard the vessel. The bright yellow tag, placed like a bridle on the fish, seemed to be one of the most visible tags used so far. Unfortunately, such was not

Table 8

Comparison of points of discovery for haddock tags

Where found	Chatham				Offshore tagging					
	Petersen tags		Combination tags		Petersen tags				Spaghetti tags	
					Operculum		Dorsal			
	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)	(No.)	(%)
en caught	14	22.2	25	15.8	18	32.7	4	13.4	7	10.4
ndling on vessel	29	46.0	70	44.3	16	29.1	3	10.0	16	23.9
loading	1	1.6	7	4.4	4	7.3	1	3.3	6	9.0
ocessing ashore	10	15.9	14	8.9	10	18.2	18	60.0	25	37.3
tail store	6	9.5	30	19.0	—	—	1	3.3	4	6.0
vate home	1	1.6	2	1.3	—	—	—	—	—	—
known	2	3.2	10*	6.3	7	12.7	3	10.0	9	13.4
tal	63	100.	158	100.	55	100.	30	100.	67	100.

* Includes 2 found on beach.

the case. Only 34 percent of the spaghetti tags were discovered aboard ship. More than 60 percent of the operculum Petersen tags and 23 percent of the dorsal Petersen tags were thus discovered.

Dorsally placed tags apparently are not readily noticed aboard ship. Possibly this is because the fishermen commonly grasp the fish by the head, with its belly up, when it is handled for ripping and gutting. Thus the dorsally placed tag is hidden. Workers in processing plants discovered 60 percent of the dorsal Petersen tags, 37 percent of the spaghetti tags, and less than 20 percent of the operculum Petersen tags. One dorsal Petersen tag and four spaghetti tags reached the retail market before they were seen and reported. Presumably these fish entered the dressed fish market, since it would be impossible to fillet them without seeing the tag. A few of the dorsal Petersen tags became imbedded in the dorsal musculature through subsequent growth of the fish and were not readily visible. None of the spaghetti tags returned to date were faded; the color was still as bright as when the tag was attached, thus there was no problem of decreased tag visibility. Human carelessness, or indifference, is undoubtedly a big factor contributing to reduced or tardy tag discovery.

Time of year. — During the analysis of the Chatham tagging data, an apparent relationship was seen between the time of year when the fish were tagged and the percentage of returns. The highest return rate (17.3 percent) was for fish tagged in the spring (April), the second highest (11.3 percent) was for fish tagged in the winter (November and December), while the lowest (6.5 percent) was for fish tagged in the summer (July and August) (Table 9).

Table 9

Tagging success and season of the year, Chatham, 1953—1954

Season	Tag	Number: Fish tagged		Number: Tags returned		Rate of return (%)	
Winter	Petersen	232	697	22	79	9.5	11.3
	Combination	465		57		12.3	
Spring	Petersen	200	608	26	105	13.0	17.3
	Combination	408		79		19.3	
Summer	Petersen	185	565	15	37	8.1	6.5
	Combination	380		22		5.8	
Total	Petersen	617		63		10.2	
	Combination	1253		158		12.6	

Two factors are considered to explain the differential returns: (1) the effect of the water temperature, and (2) the condition of the haddock in springtime. It is possible that the cool isothermal water column which prevails in the spring (and to some extent in the latter part of the winter) does not add a physiological shock to the physical shock that occurs when the
is hauled from the bottom to the surface for tagg
Another possibility, suggested by Parker, Black,
Larkin (this symposium, No. 19), lies in the fact
haddock spawn in the spring. Parker and his gr
working with salmon, reported that death due
fatigue may be avoided and the survival of mar
fish enhanced if tagging is restricted to the spawn
season.

The influence of time of year is further dem
strated by our successful springtime tagging with
caught in an otter trawl in the experiment descri
in this paper, and the lack of success, under sim
tagging conditions, of experiments conducted
other times of the year (Fish and Wildlife Ser
unpublished data). The failure of the haddock tagg
conducted in September 1950 aboard the *Albatross*
described in this paper, was probably due to
time of year when the experiment took place.

Ease of tag attachment. — Although we made
precise studies of the time needed to attach
different kinds of tags, it was evident that some w
attached with greater ease than others. The t
varied with the skill of the operator, too, but in n
cases the spaghetti tag was attached in less time t
the others. Thus, haddock tagged with spaghetti
were out of water a shorter time, which may be
of the reasons for the success of this tag.

Conclusion

Petersen tags and combination tags. — The pre
tagging studies did not distinguish any one tag t
as superior for marking haddock. For studies of
than 3 years, the Petersen tag on the opercu
seems to yield the greatest number of returns.
longer studies the combination tag is better, altho
there is probably greater initial tagging morta
with this tag than with the Petersen tag. Neither
shows any special advantage in studies where pre
recovery locations are wanted, since both were fo
aboard ship at about the same rate; also, about the sa
percentage of both tags escape the fishermen's no
to be found in processing plants and markets. M
combination tags were discovered in retail mark
thus greatly reducing the likelihood of tracing
tag back to the vessel and so learning the positio
which the tagged fish was first captured.

Petersen tags and spaghetti tags. — The offsh
tagging again showed the Petersen tag on the o
culum to be better for short-term studies.
spaghetti tag yielded a high percentage of ret
over a 3-year period and did not seem to cause
initial tagging mortality characteristic of the com
nation tag tested off Chatham.

There is little to recommend the Petersen
attached through the dorsal musculature. Altho

did yield a substantial percentage of returns from eorges Bank tagging, many of the tags were not scovered until the fish were in the shore processing ants.

Successful haddock tagging from an otter trawler quires that the tagging be done when the water cold and isothermal. In the Georges Bank-Gulf of laine region this occurs in the spring. The uni-rmly cold water apparently minimizes physiological mage to the fish and probably reduces the initial gging mortality. Placing the fish for tagging in nks with running sea water, and selecting only the veliest individuals, further increases the chances for eater recaptures.

On the basis of the evidence presented here, the aghetti tag is the most promising for future haddock gging. It is easily attached to the fish and does not use sores at the point of attachment. It cannot be ergrown with tissue as with the Petersen tag and, though we have no direct evidence, it probably is t easily shed.

Summary

1. Previous haddock tagging experiments in the ulf of Maine area had been largely unsuccessful, ith few or no returns. Tagging experiments with h caught in otter trawls had been especially un-ccessful. Refinements in tag materials and tagging chniques, however, led to two large-scale tagging periments.

2. In 1953 and 1954, haddock caught by line awls in waters off Chatham, Massachusetts, were gged as follows: 617 with Petersen tags on the perculum, and 1,253 with a combination internal chor-hydrostatic capsule tag.

3. In the early spring of 1957, haddock caught in otter trawl on Georges and Browns Banks were gged as follows: Georges Bank; 297 with Petersen gs on the operculum, 179 with Petersen tags on the rsum, and 221 with spaghetti tags on the dorsum: owns Bank; 640 with Petersen tags on the operculum, 9 with Petersen tags on the dorsum, and 272 with aghetti tags on the dorsum.

4. Returns from the Chatham experiment yielded (10.2 percent) Petersen tags and 158 (12.6 percent) mbination tags.

5. The spaghetti tags yielded a higher rate of turn than the Petersen tags in the offshore haddock gging experiments. On Georges Bank, 21 (7.1 per-nt) Petersen tags on the operculum, 20 (11.2 per-nt) Petersen tags on the dorsum, and 33 (14.9 per-nt) spaghetti tags were returned. On Browns Bank, (5.5 percent) Petersen tags on the operculum, (2.5 percent) Petersen tags on the dorsum, and (12.9 percent) spaghetti tags were returned.

6. All of the tags tested on the offshore banks tended to inhibit the growth of the tagged fish.

7. The two kinds of tags used in the Chatham experiment were equally visible to the fishermen, since 68 percent of the Petersen tags and 60 percent of the combination tags were discovered aboard ship. The remainder were discovered ashore, at the dock, in the filleting plant, or in a retail market.

In the offshore tagging, 62 percent of the Petersen tags on the operculum, 23 percent of the Petersen tags on the dorsum, and 34 percent of the spaghetti tags were discovered aboard ship. Tags attached dorsally apparently are not easily seen by the fishermen.

8. The highest rate of tag returns came from fish tagged in the spring.

9. The experiments did not demonstrate that any one tag was vastly superior for haddock tagging. However, the spaghetti tag is recommended over the others because it is easily attached, does not irritate the tissues at the point of attachment, cannot be overgrown with tissue, is probably not easily shed, and remains on the fish at least 4 years.

Acknowledgements

The tagging experiments described herein were carried out under the leadership of John R. Clark. John P. Wise and Sterling L. Cogswell assisted with much of the field work.

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Schmidt & Klaunig, Kiel

Experience Paper No. 14

CHANGES IN AVAILABILITY OF ALBACORE IN THE EASTERN PACIFIC OCEAN 1952 and 1958

by

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Abstract

Environmental conditions and albacore catch and landing records were examined for 1952 and 1958. Changes in distribution of albacore in the coastal waters of North America for these two years appear to be related to differences in oceanographic features which were apparent not only over the region of the fishery but over a large portion of the central north Pacific Ocean. The possibility that differences in oceanographic conditions were related to contrasting atmospheric features for the two years is discussed.

VARIATIONS DES DISPONIBILITES EN GERMONS DANS LA PARTIE EST DE L'OCEAN PACIFIQUE, 1952 ET 1958

Résumé

On a examiné pour 1952 et 1958 les conditions du milieu ainsi que les statistiques des prises et des apports de germons. La comparaison entre ces deux années a fait apparaître dans la répartition des germons des eaux côtières d'Amérique du Nord des modifications semblant en rapport avec des différences dans les caractéristiques océanographiques, qui se sont manifestées non seulement sur les lieux de pêche, mais dans une large portion de la partie centrale du Pacifique Nord. Le document examine la possibilité que ces différences soient rattachées à la diversité des conditions atmosphériques de ces deux années.

VARIACIONES EN LA DISPONIBILIDAD DE LA ALBACORA EN EL PACIFICO ORIENTAL EN 1952 Y 1958

Extracto

Examinados los datos de captura y desembarque de albacora y las condiciones ambientales de 1952 y 1958, resulta que las variaciones experimentadas durante esos dos años por la distribución de la albacora en las aguas costeras de Norteamérica guardaban relación con las variables características oceanográficas, manifestadas no sólo en la zona de la pesquería, sino también sobre una vasta extensión del Pacífico centro-septentrional. Se discute aquí la posibilidad de correlación entre las diferentes condiciones oceanográficas y las contrastantes características atmosféricas de aquellos dos años.

INTRODUCTION

Landings of albacore (*Thunnus germo*) in ed States ports over the decade 1950 to 1959 ged from 26.72 million pounds in 1954 to 71.60 ion pounds in 1950. More striking than fluctuation in total landings, however, is the ation that has occurred in distribution of core in North American coastal waters as uced from landing and catch distribution rds.

Annual variations in landings of albacore in ed States ports depend upon abundance of core in the northeastern Pacific Ocean, fish- effort expended to harvest this fish and its lability to the fisherman. For purposes of paper, abundance is defined as the absolute ber of individuals in a population, and avail- ity as variation in catch not associated with dance or fishing intensity, but rather with ation in environmental factors (Marr 1951).

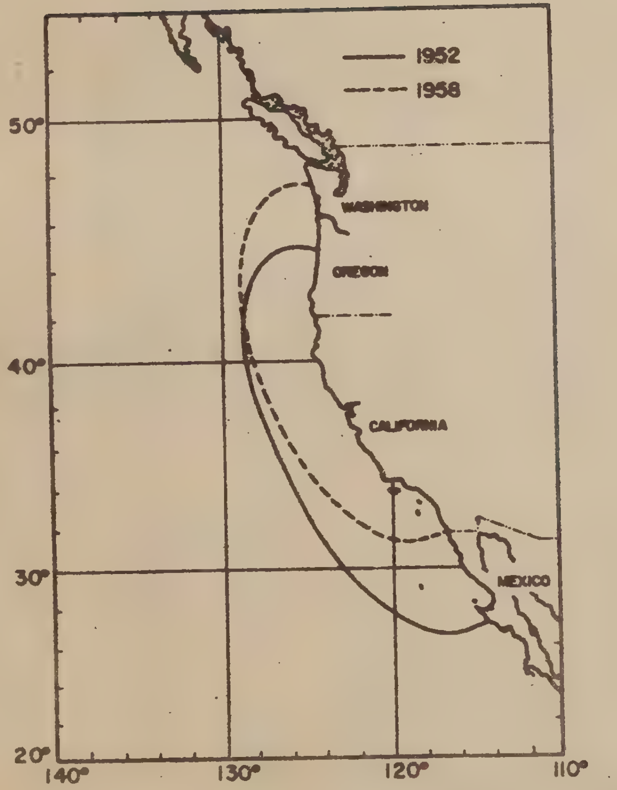
Although variations in abundance probably ct the success of the fishery from year to r, assessment of the effect of changes of dance on the albacore fishery has not yet established; nor have investigations been lucted to assess the effect of annual variations shing intensity on the fishery. Recent stud- however, have shown that variations in the n climate alter distribution of albacore in northeastern Pacific (Hester 1961; Radovich Johnson 1962) which in turn have affected lability for different regions over which the ery is carried out. The intent here is to yze environmental conditions and catch rds for 1952 and 1958, years when changes tch location of albacore were clearly evident . 1), and to suggest that changes in availab- at the southern and northern ranges of the ery in coastal waters of North America may been caused by differences in environmental itions for the two years. For purposes of paper, a southern fishery is defined as that ied out south of the International Border be- n Mexico and the United States, and a north- fishery as that occurring north of the fornia-Oregon border.

ALBACORE FISHERIES AND MIGRATIONS IN THE NORTH PACIFIC

Recent tagging experiments indicate that the core of the north Pacific Ocean belong to one ulation (Otsu 1960; Clemens 1961). During a od of a year, parts of this population are fished throughout temperate waters. The Japanese live-bait fishery occurs in coastal waters of Japan during the spring and early summer and follows closely the Japanese winter longline fishery of the western and central north Pacific (Van Campen 1960). The live-bait and troll fishery of the north eastern Pacific occurs in coastal waters of North America in the summer and autumn (Clemens 1955).

Otsu and Uchida (1961) postulate a center of abundance in the central north Pacific through and from which the albacore migrate into the three fisheries. During its lifetime an individual albacore may have been subjected to all three fisheries. According to McGary, Graham and Otsu (1961) the eastward migration is spring and summer toward the American coast is related to the 55° to 65°F band of water of the Transition Zone defined by Hida (1957) as "an area of mixed fauna and variable biomass between the Subtropic and Subarctic Zones". Clemens (1955) has found that first arrival of migrants into the American fishery usually occurs in June. Craig and Caneday (1962) believe that the early season migration may take place in the California Current, which is the eastern southward-flowing part of the large clockwise circulatory system of the north Pacific. Because water in the surface layer is transported from north to south in this current, it can be identified off southern California and Baja California by its low temperature-low salinity characteristics. Considerable variations exist from year to year in the strength of the California Current (Reid, Roden, and Wyllie 1958), and the southern limit of the albacore fishery each year appears to be related in part to these variations. In years when the current is strong, that is, when low temperature-low salinity water penetrates farther to the south than usual, albacore are found farther to the south. In years of a weak current the albacore appear farther to the north.

Clemens (1961) has found that, as a rule, the southern extent of best fishing is limited by about the 66° or 67°F isotherm. Because of lack of adequate fishing records, extent of the northern fishery off Oregon and Washington in relation to the environment is more difficult to define. Johnson (1960) and Flittner (1961) have found from Navy vessels cooperating with the U.S. Bureau of Commercial Fisheries in a trolling program that the northward advance of 59° to 60°F water is accompanied by northward distribution of albacore; and Alverson (1961), summarizing north Pacific albacore surveys,


1952
1958
WASHINGTON
OREGON
CALIFORNIA
MEXICO
50°
40°
30°
20°
140°
130°
120°
110°

General region of the albacore fishery in coastal waters of the United States for 1952 and 1958

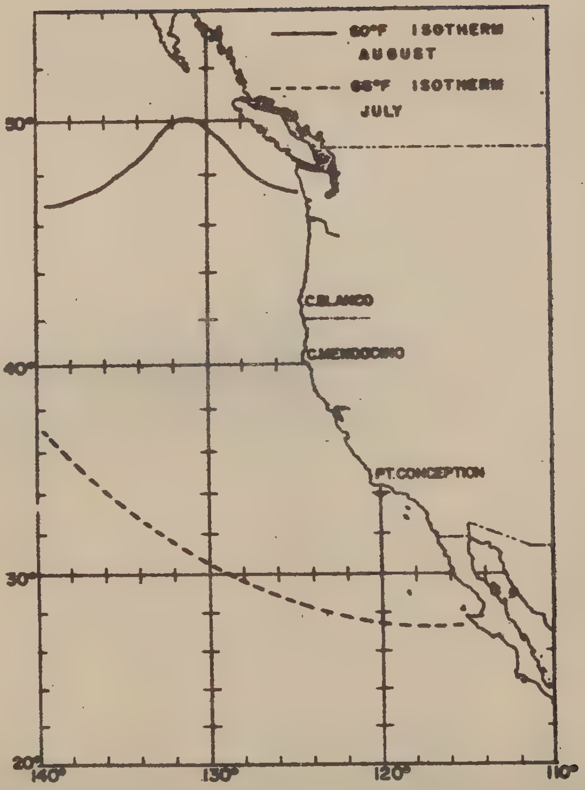

60°F ISOTHERM AUGUST
66°F ISOTHERM JULY
C.BLANCO
C.MENDOCINO
PT.CONCEPTION
50°
40°
30°
20°
140°
130°
120°
110°

Fig. 2 Normal southern limit of 66°F isotherm in July and normal northern limit of 60° F isotherm in August based on sea temperature data for 1947 to 1958

ound best fishing occurred in about 60°F water.

The most southern limit of the fishery sually occurs in July or August (Clemens 955); in July the 66° F isotherm normally ntersects the North American mainland at bout latitude 27° N (Fig. 2). The most orthern extent of the fishery usually occurs n August at which time the 60° F isotherm ears 50° N at about 130° W. The commercial ishery for albacore to the north, however, is onducted inshore of 130° W; the 60° isotherm n the general region of the fishery reaches bout 47° N (Fig. 2).

SOUTHERN FISHERY, 1952 and 1958

Over the ten-year period 1950 to 1959, an verage of 16.26 million pounds of albacore have een taken from south of the International order (Table I). The highest landings from hat area for the ten years occurred in 1952 hen 26.70 million pounds were landed. lemens (1955) shows that in 1952 albacore were aken in abundance as far as four hundred miles outh of the border. In contrast to the favorable ishery of 1952, the fishery in 1958 was nearly a omplete failure; only 0.72 million pounds were anded from south of the border. Catch distriution records are not available for 1958 but ishermen have indicated that the fishery barely enetrated the region south of the border.

The difference in landings for 1952 and 1958 or the region south of the border was accomanied by markedly different oceanographic onditions. In July 1952, 10 m water temperaures were much colder than the 1950 to 1959 verage. Off Punta Eugenia, temperatures were s much as 8 F colder than the average (Fig. 3). he "cold" water was accompanied by salinity alues that ranged considerably below average. he combination of low temperature-low salinity ater suggests presence of California Current ater. In July 1958, conditions were opposite; oth temperatures and salinities were for the ost part above average (Fig. 3), which suggests educed influence of California Current water.

NORTHERN FISHERY, 1952 AND 1958

Although catch distribution records for the oastal region north of the California-Oregon order are not available, indication of the uccess and range of the fishery from that egion can be obtained by examination of landing ecords. In 1952, only 2.76 million pounds of albacore were landed in Oregon-Washington ports as against 11.26 million pounds in 1958 (Table I). Furthermore, the fact that over a million pounds were taken by boats operating north of the California-Oregon border in 1958 and landed in California ports, as opposed to no landings in this category in 1952, is suggestive of a more northern fishery in 1958 (Table I).

Statements in the literature also support a more northern fishery in 1958 than in 1952. An exploratory fishery cruise in 1952 by the research vessel *John N. Cobb* found albacore scarce throughout coastal waters of Oregon and Washington and offshore to about five hundred miles (Schaefers 1953). Pacific Fisherman Yearbook (1953) notes that albacore fishing in 1952 off the coast of Washington was virtually blank and that Oregon waters yielded little. In 1958, however, fishermen found the best albacore run in years off Pacific northwest states (Pacific Fisherman Yearbook 1959); in fact, a few albacore were taken in the Gulf of Alaska by vessels trolling for salmon (Pacific Fisherman 1958).

Extensive oceanographic data are not available for 1952 and 1958 for coastal waters of Oregon and Washington. Oceanographic conditions for the two years as indicated by sea surface temperatures, however, were markedly different. In 1952 when the fishery was poor, August temperatures were appreciably below average, and in 1958, when the fishery was a success, August temperatures were above average (Fig. 4).

5 DISCUSSION

Oceanographic conditions that may have caused the differences in distribution of albacore in 1952 and 1958 were established well before the fishing season began in July. Ten-meter temperature and salinity anomalies for the region south of the International Border for April 1952 and April 1958 were similar to those in July (Fig. 3). Sea-surface temperature anomaly charts of coastal regions of North America show that the first six months of 1952 was characterized by "cold" water in the northeastern Pacific, whereas for the first half of 1958 "warm" water was widespread (Johnson 1961).

Differences in oceanographic conditions between the two years were not limited to the area contiguous to North America but occurred also in much of the central north Pacific Ocean.

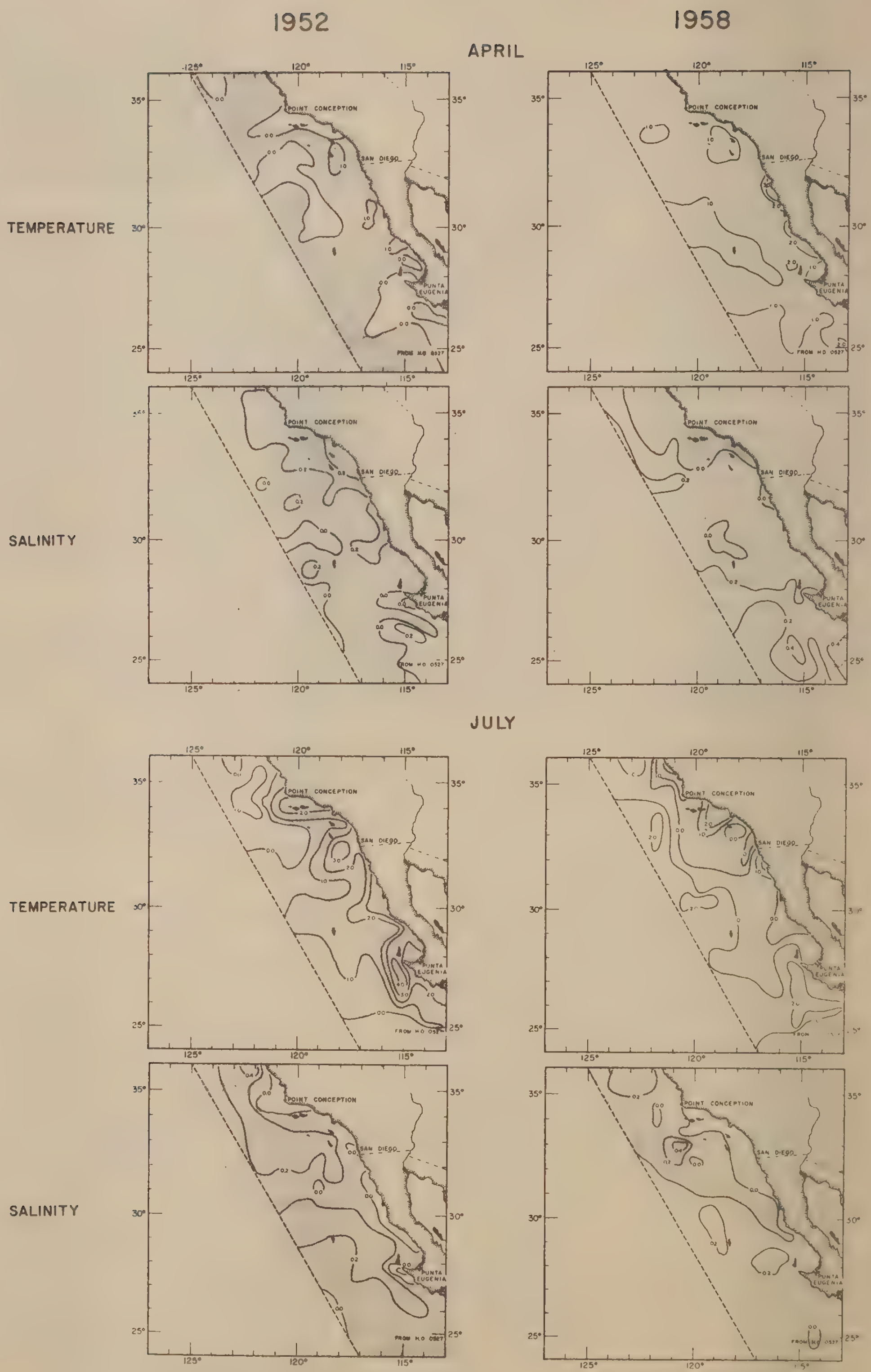

1952
1958
APRIL
JULY
TEMPERATURE
SALINITY
TEMPERATURE
SALINITY
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
FROM H.O. 0527
125°
120°
115°
35°
30°
25°

Fig. 3 Ten-meter temperature and salinity anomalies for April and July, 1952 and 1958, based on 1950 to 1959 averages. Contour interval for temperatures 2° F and for salinities 0.2°/oo. Shaded areas indicate temperatures and salinities below average.

Table I

Landings of albacore in United States ports, in millions of pounds, 1950 to 1959[1]

Year	Landings in California from south of International Border between Mexico and United States	Landings in California from California waters	Landings in California from north of California-Oregon Border	Landings in Oregon and Washington	Total U.S. landings
1950	23.60	38.14	0.08	9.78	71.60
1951	17.62	13.28	0.01	3.44	34.35
1952	26.70	23.10	0.00	2.76	52.56
1953	20.49	13.30	0.05	0.81	34.65
1954	11.82	14.29	0.00	0.61	26.72
1955	19.69	9.31	0.00	0.70	29.70
1956	21.06	15.87	0.12	4.28	41.33
1957	20.91	22.61	0.00	3.06	46.58
1958	0.72	25.39	1.08	11.26	38.45
1959	0.00	32.52	0.22	13.54	46.28
Average	16.26	20.78	0.16	5.02	42.22

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[1] Source - Calif. Dept. Fish and Game, Marine Resources Operations; Pacific Fisherman Yearbook 1961.

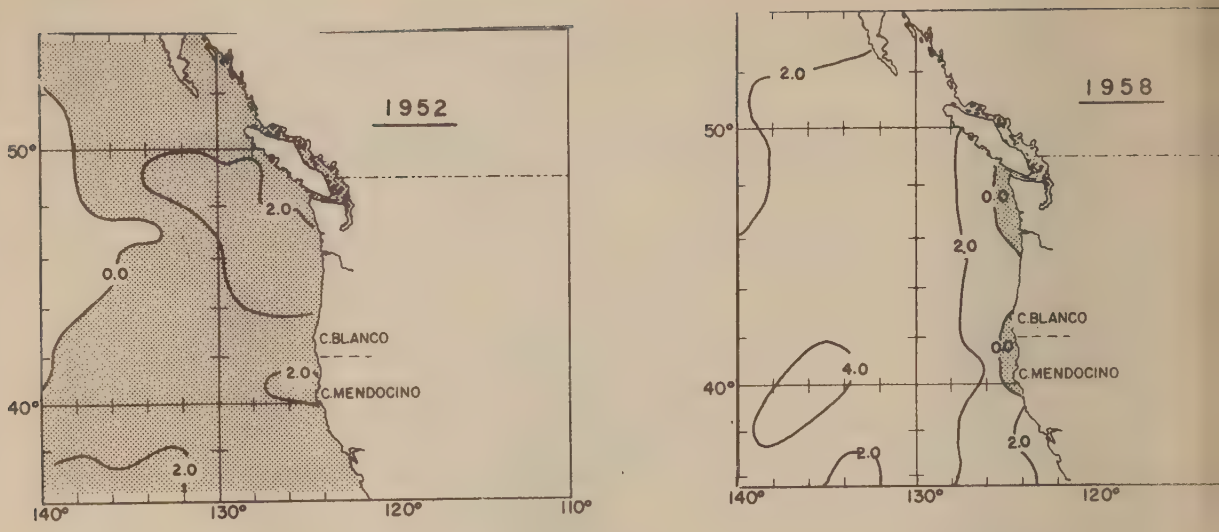
1952
50°
40°
2.0
0.0
2.0
2.0
C.BLANCO
C.MENDOCINO
140°
130°
120°
110°
1958
50°
40°
2.0
0.0
2.0
0.0
4.0
2.0
2.0
C.BLANCO
C.MENDOCINO
140°
130°
120°

Fig. 4 Sea-surface temperature anomalies for August 1952 and 1958, based on 1947 to 1958 average. Contour interval 2 °F. Shaded areas colder than average.

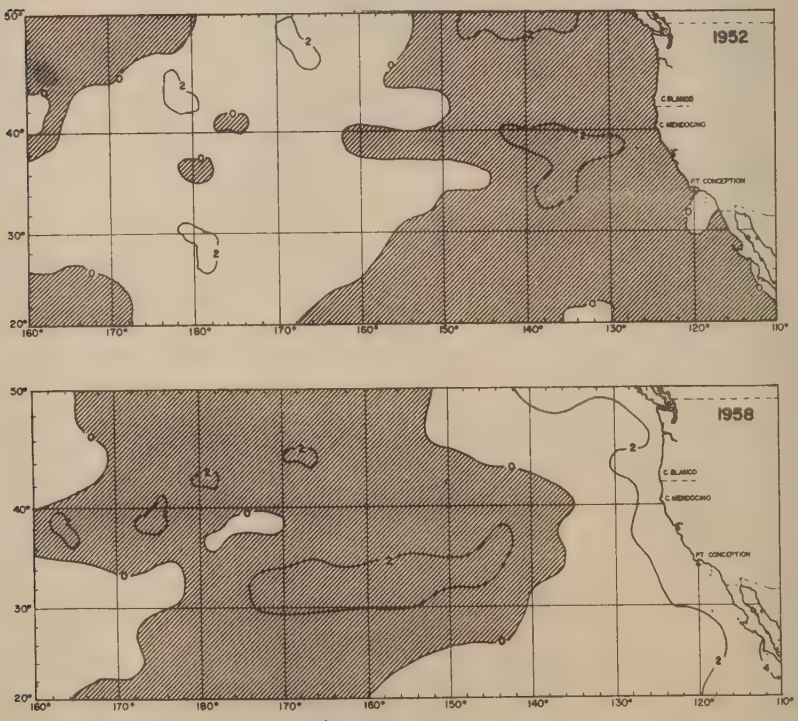
1952
50°
40°
30°
20°
0
2
C.BLANCO
C.MENDOCINO
PT CONCEPTION
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
1958
50°
40°
30°
20°
0
2
4
C.BLANCO
C.MENDOCINO
PT CONCEPTION
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°

Fig. 5 Sea-surface temperature anomalies for the central and eastern north Pacific Ocean for March, April, and May 1952 and 1958.

arch, April and May of 1952, water warmer
the 1947-1958 mean covered a vast area of
central north Pacific. The anomaly in 1958
the same general region was appreciably
ow normal (Fig. 5).

Over the past few years, increased emphasis
been placed on studies of the underlying
ses of sea-temperature anomalies. Once
se causes are understood, it may be possible
redict distribution of albacore on a broad-
le basis. Even now predictions of a general
ure have been made possible because Roden
Reid (1961) have found that large-scale sea-
perature anomalies usually persist from
ee to six months.

Uda (1961) has studied albacore fisheries of
eastern and western Pacific and has recog-
ed a reciprocal relation between the catch in
western Pacific and the catch in the eastern
ific. He has explained this reciprocal re-
nship on sea-temperature trends which also
e found by him to vary inversely. The var-
ons in sea temperatures were further related
luctuations in atmospheric pressure systems
r the north Pacific (Uda 1960).

Examining sea temperature and sea level
ospheric pressure data for the north Pacific,
len and Reid (1961) found agreement, in some
es, in anomalous pressures of the Pacific and
malous temperatures. They noted that in
uary 1958 the central north Pacific was dom-
ted by a large negative pressure anomaly in
region of the Aleutian low. From this they
uced increased southerly winds in the north-
tern Pacific resulting in positive sea-temp-
ture anomalies along the Pacific Coast of
th America. Namias (1959) also noted the
ge positive sea-temperature anomaly in the
tern Pacific in 1958, and he concluded that
feature might be related to prevailing abnor-
lities in the atmospheric circulation caused
an eastern Pacific anticyclone much weaker
n normal and prevailing westerly winds dis-
ced much farther south than normal. He
pared observed sea-temperature anomalies
n computed wind-induced advective anomalies,
ng sea-level pressures, and found general
eement between the two in the winter 1957 to
3 for the northeastern Pacific. Eber (1961)
urther analysis of conditions in the winter
7 to 1958 concurred that wind-induced advec-
may have resulted in the positive temperature
maly.

Reid, Roden, and Wyllie (1958) indicate that for 1952 the north component of the wind computed from atmospheric pressure difference at 30°N between 110°-130°W was stronger than normal; and from an analysis of a system of pressure indices by Eber and Sette (1959), the conclusion can be drawn that winds over the California Current in 1952 were more intense than normal. These findings suggest increased advection of cold-low salinity water in the California Current which is consistent with data presented in Fig. 3 and movement of albacore to the south. Eber and Sette (1959) pointed out that their pressure indices for the winter months for 1946 to 1955 reflected a higher average intensity and more northerly mean position of the eastern north Pacific high compared with the two earlier decades.

Progress that has been made in recent years in relating distribution of albacore to broad-scale changes in the ocean climate, and the fact that some of these changes appear to have been related to variations in the atmosphere, lend credence to the prediction that those studying the time and space distribution of the albacore will turn increasingly to investigations of processes at the air-sea boundary. In the final analysis, the complex nature of changes in distribution of albacore appear inextricably related to both the ocean and the atmosphere.

6 ACKNOWLEDGEMENTS

Thanks are given to the Data Collection and Processing Group of Scripps Institution of Oceanography for use of sea-temperature and salinity averages (1950 to 1959) compiled from California Cooperative Oceanic Fisheries Investigation Reports, and to Oscar E. Sette, Gerald V. Howard, Laurence E. Eber, and Glen A. Flittner of the U. S. Bureau of Commercial Fisheries, for suggestions regarding the preparation of this report.

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Reprinted from Science, February 22, 1963, Vol. 139, No. 3556, pages 764-766

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ctopus violaceus Uses lia Tentacles as Weapons

tract. *Immature octopods* (Trem-
s violaceus) *have been found*
umerous fragments of tentacles
coelenterate Physalia *attached to*
ckers of their dorsal arms. The
le method of acquisition, the evi-
of adaptation for holding the
es, and the possibility that the
d uses these coelenterate tenta-
offensive and defensive weapons
scussed.

eral workers (*1*, *2*) have reported
currence of portions of unidenti-
oelenterate tentacles on the arms
ng *Tremoctopus violaceus* Delle
(Cephalopoda: Tremoctopo-
, a pelagic octopod. Naef (*2*)
nable to determine whether this
ation was the accidental result of
counter with the coelenterate or
dvantageous behavior pattern
by the stinging cells could be used
apons by the octopod. He pro-
that the latter was probably the

s report presents some similar
ations in which the coelenterate
ents are identified, and Naef's hy-
sis of an advantageous behavior
n is supported.

ring cruise No. 38 of the Bureau
mmercial Fisheries' research ves-
ugh M. Smith in February 1957,
light stations were conducted in
cinity of latitude 13°S, longitude
to 112°W. Among the frequent
s to the submerged light were a
er of immature female octopods,
ctopus violaceus. I dip-netted one
se from the water and lifted it
nd out of the net. I experienced
n and severe pain and involun-
threw the octopod back into the
. To determine the mechanism
nsible for this sensation 10 or 12
(40 to 72 mm total length)
ods were captured and I purposely
l each one on the tender areas of
ands. The severe pain occurred
time, but careful observation indi-
that I was not being bitten by
ctopod. The pain and the resulting
ng and inflammation, which lasted
l days, resembled the stings of
oelenterate *Physalia*, the Portu-
man-of-war, which was quite
lant in the area.

sequent examination of one of
female octopods, 72 mm long,
had been preserved, revealed fragments of *Physalia* tentacles attached in an orderly fashion to each row of suckers of each of its four dorsal arms (Fig. 1*a*). No tentacles were found on any of the four ventral arms.

About 75 percent of the suckers of each dorsal arm carried *Physalia* fragments. The unoccupied suckers were, for the most part, those near the base and the distal tips of the arms. This degree of occupation of the suckers would render these arms nonfunctional as conventional grasping organs.

Although each fragment was grasped by several suckers in such a manner that there was a minimum of contact between it and the tissue of the octopod, microscopic examination indicated that a number of discharged nematocysts had their tubes embedded in the tissue of the octopod suckers. Thus it appears that *Tremoctopus* is either immune to the toxin of *Physalia* or is able to confine it to insensitive tissue. That such immunity is possible is supported by at least three records of animals that eat *Physalia.* These are the loggerhead turtle (*3*), the marlin (*4*), and the Portuguese man-of-war fish (*5*). However, examination of the stomach contents of a 40-mm female octopod which carried tentacle fragments on its arms revealed no coelenterate material.

There is evidence that the structure of the suckers of the arms of *Tremoctopus* is adapted for holding coelenterate fragments. A diagrammatic lateral view of the suckers of the ventral arm shows that they are cylindrical with an elongate capsule cavity, an unconstricted opening, and a large distal surface apparently suitable for adhesion to a plane surface (Fig. 1*b*). The capsule of the sucker of the dorsal arm is similar to a small bulb, rounded, with a very small opening and with no flat distal surface (Fig. 1*c*). The manner of grasping the *Physalia* fragments by the suckers of these dorsal arms is indicated in Fig. 1*d*, which shows a fragment which has been teased loose from three suckers. The tissue of this fragment shows that it was drawn out by suction into three small pedunculate diverticula which just filled the capsule cavities.

While from experience, I can personally testify to the efficacy of the coelenterate fragments on the octopod's arms as a means of defense, there is some evidence that defense is not the only function of these stinging tissues. The suckers of cephalopods are generally used as offensive weapons, that is, for capturing food, and some species have well-developed chitinous teeth or

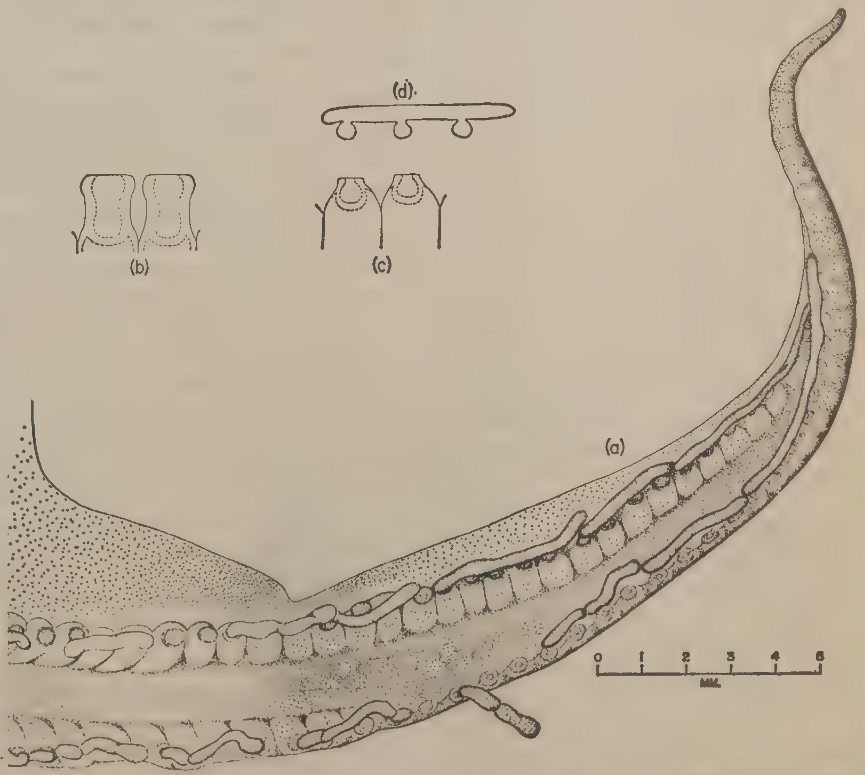

Fig. 1. (*a*) Dorsal arm of *Tremoctopus*, with *Physalia* fragments; (*b*) diagrammatic lateral view of a sucker of a ventral arm; (*c*) diagrammatic lateral view of a sucker of a dorsal arm; (*d*) *Physalia* fragment showing diverticula.

hooks in the sucker rings which add to the animal's ability to catch and hold its prey. Defensive behavior in cephalopods usually involves color changes, the use of ink as a decoy or screen, and agility in jumping and jetting. With these considerations in mind, it appears quite possible that *Tremoctopus* may utilize *Physalia* tentacles as offensive weapons. Berry's illustrations of the female *Tremoctopus violaceus* (*6*) suggest that the four dorsal arms with their connecting web may form a coarse straining mechanism. With every row of suckers of such a mechanism armed with tissue capable of stinging, the entire arrangement could be quite effective in capturing plankton or small fish. The tentacles of *Physalia,* with their stinging cells, are quite adhesive and the action of these stings on fish quickly renders them quiet and helpless (*7*).

It is interesting to speculate on the method *Tremoctopus* might use in obtaining the tentacle fragments. Unless the octopod is immune to *Physalia* toxin, the approach to the coelenterate must be made quite cautiously, and one can only imagine the pickpocket type of dexterity which would be required to obtain enough tentacle fragments to cover eight rows of suckers. The arrangement in single-file rows of the tentacle fragments on the arms suggests that the oral surface of a dorsal arm of the octopod is moved to a position parallel with an extended *Physalia* tentacle and then the small suckers are attached to a long section of the tentacle. It appears from their rounded ends that the fragmentation of the tentacles may have been the result of autotomy.

Certain observed behavior patterns in *Tremoctopus* and *Argonauta* octopods may explain the origin of carrying *Physalia* fragments by the former. During the same cruise on which the specimen shown in Fig. 1*a* was collected, several small specimens of *Tremoctopus* were kept in an aquarium containing circulating sea water. They were frequently observed attached to the sides or bottom of the vessel or crawling about in a manner similar to that of more conventional benthic octopuses.

A small mature female *Argonauta hians* Solander with a brood shell was also observed for a period of nearly a month and it spent considerable time attached to the sides or the bottom of the aquarium. This argonaut was captured while it was attached to a floating siphonophore, *Velella.* E. L. Nakamura (*8*) in 1952 captured three small female argonauts, each of which was attached to the exumbrella of a medusa (*Pelagia placenta* Haeckel) which was drifting near the surface of the water. Bruun *et al.* (*9*) reported similar observations from the Indian Ocean. These reports suggest that pelagic octopods of the families Tremoctopodidae and Argonautidae are not strong swimmers and rest by attaching themselves to buoyant coelenterates. Such close association might lead to immunity from the coelenterate toxin and to the acquisition of the tentacle fragments by *Tremoctopus.* No coelenterate fragments were found, however, on a number of argonauts which were examined.

The behavior of holding *Physalia* fragments has been observed only in young *Tremoctopus,* and it is not known whether it persists in the adult. Voss (*10*) has stated that *T. violaceus* may exceed 5 feet in total length and in his collection he has (*11*) a preserved 4-foot egg-bearing female. These reports of large-sized specimens indicate that a female of 72 mm total length is almost certainly immature. Two immature males, 30 mm in total length, with the hectocotylized arm still within a sac, are in the collection of the Biological Laboratory, Honolulu, and each is carrying *Physalia* fragments on its dorsal arms.

Various other marine animals are known to employ coelenterates or their stinging cells as defensive weapons. Among these are hermit crabs; brachyuran crabs, which carry an anemone in each cheliped; and flatworms and nudibranchs, which carry coelenterate nematocysts in their dorsal filaments. *Tremoctopus* appears to be unique in its use of such potent tissue as the nematocysts of *Physalia* and, if my hypothesis is correct, in employing such tissue as an offensive as well as defensive weapon. It is perhaps unique also in its use of only parts of coelenterates as weapons. This may imply an ability to determine when replacement is necessary.

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19 November 1962

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Use of Alkalinity and Conductivity Measurements to Estimate Concentrations of -Trifluormethyl-4-Nitrophenol Required for Treating Lamprey Streams.

at Lakes Fishery Commission

ICAL REPORT No. 7
ber, 1963

The Great Lakes Fishery Commission was established by the Convention on Great Lakes Fisheries, between Canada and the United States, ratified on October 11, 1955. It was organized in April, 1956 and assumed its duties as set forth in the Convention on July 1, 1956. The Commission has two major responsibilities: the first, to develop co-ordinated programs of research in the Great Lakes and, on the basis of the findings, recommend measures which will permit the maximum sustained productivity of stocks of fish of common concern; the second, to formulate and implement a program to eradicate or minimize sea lamprey populations in the Great Lakes. The Commission is also required to publish or authorize the publication of scientific or other information obtained in the performance of its duties.

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THE USE OF ALKALINITY AND CONDUCTIVITY MEASUREMENTS TO ESTIMATE CONCENTRATIONS OF 3-TRIFLUORMETHYL-4-NITROPHENOL REQUIRED FOR TREATING LAMPREY STREAMS.

by

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GREAT LAKES FISHERY COMMISSION
NATURAL RESOURCES BUILDING
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ANN ARBOR, MICHIGAN

1963

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THE USE OF ALKALINITY AND CONDUCTIVITY MEASUREMENTS TO ESTIMATE CONCENTRATIONS OF 3-TRIFLUORMETHYL-4-NITROPHENOL REQUIRED FOR TREATING LAMPREY STREAMS.

Richard K. Kanayama

ABSTRACT

A method has been devised to estimate the minimum concentration of TFM that will kill sea lampreys and the maximum that will not kill fish. It is based on the relation of these concentrations to the alkalinity and conductivity of various waters. Pretreatment bioassays will continue to be required for precise determination of treatment concentrations, but the estimates made possible by the method will permit a great reduction in the number of bioassays on a single stream.

Introduction

The selective sea lamprey larvicide, 3-trifluormethyl-4-nitrophenol (TFM), has been used extensively by the U.S. Bureau of Commercial Fisheries and the Fisheries Research Board of Canada in the experimental program of sea lamprey control. The toxicity of TFM is influenced strongly by chemical and physical properties of water. As pH, conductivity, and alkalinity increase, the amount of TFM required to kill larval lampreys and rainbow trout increases (Applegate, Howell, Moffett, Johnson, and Smith, 1961). Consequently, the amount of toxicant required and the degree of selectivity of TFM between lamprey larvae and stream fishes vary from stream to stream and also with season and location within the same stream system (Howell and Marquette, 1962). This variability in toxicity necessitates the performance of bioassays prior to each larvicide application to determine the minimum concentration of TFM required to kill all lamprey larvae and the maximum concentration that can be used without causing significant fish mortality.

This report describes a method for the preliminary estimation of minimum lethal and maximum allowable concentrations of TFM. It is based on records of the relation of these treatment concentrations to the alkalinity and conductivity of the water. The estimation of biological activity of TFM by its relation to properties of water will not supplant the bioassays prior to treatments but will reduce the total number required.

The term "minimum lethal concentration" refers to the lowest concentration of TFM that kills 100 percent of the lamprey larvae in 9 hours or less, and the term "maximum allowable concentration" refers to the highest concentration of TFM that does not kill more than 25 percent of the fish in 18 to 24 hours. These two concentrations may be termed the limiting concentrations of TFM.

Materials and Methods

Data for this report were obtained from bioassays made in conjunction with chemical treatments of streams tributary to the U.S. shore of Lake Superior and the north and west shores of Lake Michigan in 1960-62.

The methods of bioassay, all carried out in mobile laboratories, were described by Howell and Marquette (1962). Phenolphthalein alkalinity and total alkalinity by the methyl-purple indicator method were determined for all bioassay test waters according to the procedures in the 11th edition of "Standard Methods for the Examination of Water and Wastewater" (1960). The results were recorded as parts per million (mg./1.) $CaCO_3$. Conductance was measured at 20° C. (68° F.) with a manually operated, A.C. conductivity bridge[1]; results were recorded in micromhos.

Relation of Water Properties to the Limiting Concentrations of TFM

Alkalinity

Alkalinity values ranged from 13 to 122 ppm $CaCO_3$ for Lake Superior and from 16 to 196 ppm $CaCO_3$ for Lake Michigan tributaries. Records for the two groups of tributaries were combined since no difference could be found between them in the relation between alkalinity and the limiting values of TFM. Only alkalinities up to 165 ppm are considered in this report due to the scarcity of data between 165 and 196 ppm. Alkalinity values were grouped by intervals of 10 ppm (10-19, 20-29, 30-39, . . .) and the means of the minimum lethal and maximum allowable TFM concentrations computed for each group (Table 1). The plot of the regression of the limiting

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[1] Industrial Instruments, Model RC-16B2, conductivity bridge.

Table 1.--Relation between alkalinity and limiting concentrations of TFM in tributaries of Lakes Superior and Michigan

[Computed values obtained from equations given in text; data shown graphically in Figure 1.]

Alkalinity (ppm $CaCO_3$)		Number of bioassays	Minimum lethal TFM (ppm)			Maximum allowable TFM (ppm)		
Interval	Mean		Computed	Actual	Difference	Computed	Actual	Difference
10- 19	16.3	10	1.2	1.0	-0.2	2.4	2.3	-0.1
20- 29	24.7	10	1.5	1.2	-0.3	3.2	3.1	-0.1
30- 39	34.4	14	1.8	1.7	-0.1	4.1	4.5	0.4
40- 49	45.4	26	2.2	2.1	-0.1	5.1	5.5	0.4
50- 59	55.1	18	2.5	2.5	0.0	6.0	6.0	0.0
60- 69	64.8	18	2.9	2.8	-0.1	6.9	5.9	-1.0
70- 79	74.8	25	3.2	3.4	0.2	7.8	7.8	0.0
80- 89	83.2	12	3.5	4.0	0.5	8.6	8.2	-0.4
90- 99	94.5	13	3.9	4.0	0.1	9.6	8.9	-0.7
100-109	105.0	19	4.3	4.7	0.4	10.6	10.9	0.3
110-119	115.3	6	4.6	4.3	-0.3	11.6	12.8	1.2
120-129	122.2	5	4.9	5.5	0.6	12.2	12.6	0.4
130-139	134.9	7	5.3	5.3	0.0	13.4	13.4	0.0
140-149	148.0	2	5.8	6.0	0.2	14.6	14.0	-0.6
150-159	157.0	3	6.1	4.7	-1.4	15.5	14.3	-1.2
160-169	163.0	5	6.3	6.7	0.4	16.0	17.0	1.0

concentrations of TFM on alkalinity indicated a straight-line relation (Fig. 1). The fitting of lines by least squares gave the equation $C_l = 0.035A + 0.6$ for the minimum lethal concentration and the equation $C_h = 0.093A + 0.856$ for the maximum allowable concentration. In these equations C_l and C_h refer to the lower and higher limiting concentrations (ppm) of TFM and A to alkalinity. Each equation fitted the original data satisfactorily.

Conductivity

Conductivity values ranged from 42.5 to 265.0 micromhos (at 20° C.) for Lake Superior tributaries and from 60.6 to 413.0 micromhos for Lake Michigan tributaries. Only conductivities up to 278 micromhos are considered in this report since few waters had higher values. Conductivity values were divided into 20-micromho groupings (40-59, 60-79, 80-99, . . .) and the means of minimum and maximum TFM concentrations obtained from corresponding bioassays were determined for each group. With conductivity as with alkalinity, it was possible to combine the data for the Lake Superior and Lake Michigan tributaries (Table 2). The plot of the data again indicated a straight-line relation (Fig. 2). Equations fitted by least squares were $C_l = 0.022M - 0.12$ for the minimum lethal and $C_h = 0.053M - 0.379$ for the maximum allowable concentrations; C_l and C_h are the same as in the previous equations and M refers to conductivity. As was true for alkalinity, the equations fitted the data most satisfactorily.

Dependability of Estimates of Limiting Concentrations

The data presented on the regression of TFM and alkalinity and conductivity clearly indicated possible usefulness of the estimates in the planning of bioassays, but judgment of the dependability of estimates could not be based on deviation of means from the regression. Dependability is better indicated by the distribution of the deviations of individual estimates from the true limiting concentrations obtained from bioassay. The distributions of errors of estimate are tabulated for the minimum lethal concentration (Table 3) and the maximum allowable concentration (Table 4) by selected intervals of TFM concentrations.

For minimum lethal concentration (Table 3), tests within the range of ± 3 ppm of the estimate seem almost certain to include the true minimum. If a lower probability averaging 97-98 percent is acceptable, testing within the range of ± 2 ppm will suffice. At the lower estimated concentrations of TFM even smaller testing ranges can be accepted.

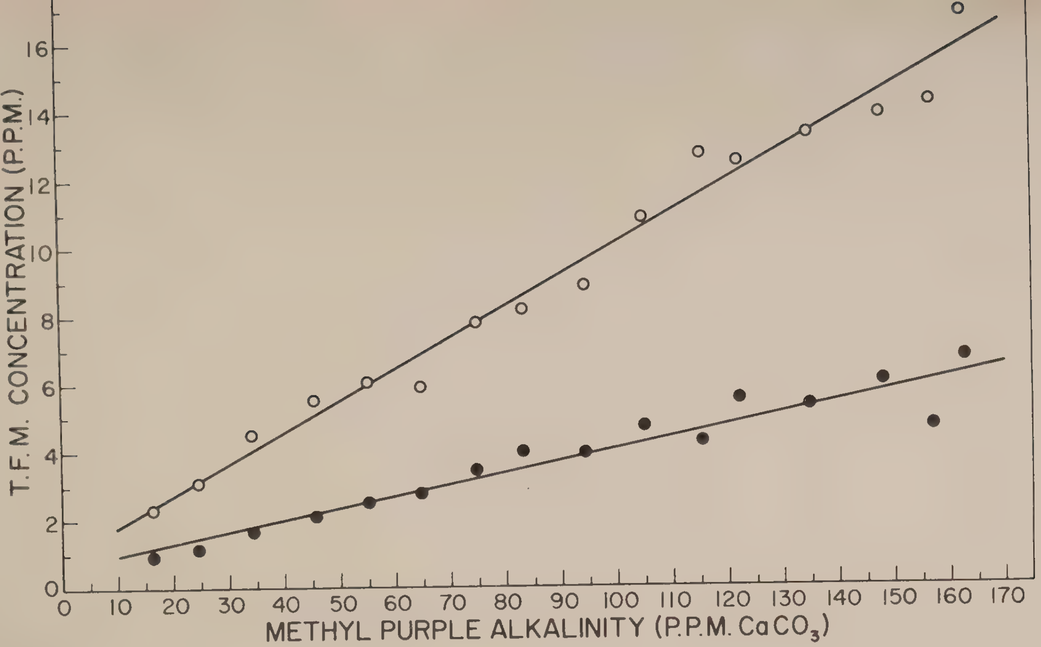

Figure 1. Relation between alkalinity and the minimum lethal (lower regression line) and maximum allowable (upper regression line) concentrations of TFM. The plotted points represent averages for groupings by intervals of alkalinity measurements (solid circles for minimum and open circles for maximum).

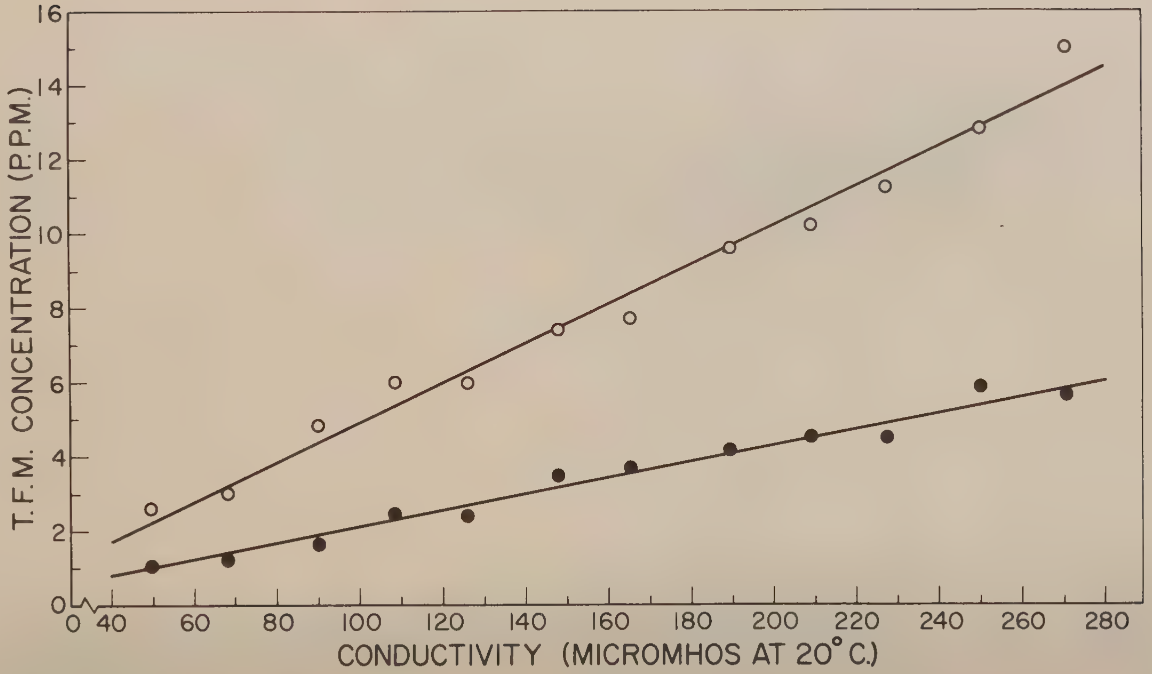

Figure 2. Relation between conductivity and the minimum lethal (lower regression line) and maximum allowable (upper regression line) concentrations of TFM. The plotted points represent averages for groupings by intervals of conductivity measurements (solid circles for minimum and open circles for maximum).

Table 2.--Relation between conductivity and limiting concentrations of TFM in tributaries of Lakes Superior and Michigan

[Computed values obtained from equations given in text; data shown graphically in Figure 2.]

Conductivity (micromhos)		Number of	Minimum lethal TFM (ppm)			Maximum allowable TFM (ppm)		
Interval	Mean	bioassays	Computed	Actual	Difference	Computed	Actual	Difference
40- 59	49.9	10	1.0	1.0	0.0	2.3	2.6	0.3
60- 79	68.5	15	1.4	1.3	-0.1	3.3	3.1	-0.2
80- 99	90.2	21	1.9	1.7	-0.2	4.4	4.8	0.4
100-119	108.8	16	2.3	2.4	0.1	5.4	6.0	0.6
120-139	126.3	22	2.7	2.5	-0.2	6.3	6.0	-0.3
140-159	148.1	22	3.1	3.4	0.3	7.5	7.4	-0.1
160-179	165.4	20	3.5	3.6	0.1	8.4	7.7	-0.7
180-199	189.7	14	4.1	4.1	0.0	9.7	9.6	-0.1
200-219	209.4	20	4.5	4.5	0.0	10.7	10.2	-0.5
220-239	227.4	12	4.9	4.5	-0.4	11.7	11.2	-0.5
240-259	250.2	4	5.4	5.8	0.4	12.9	12.8	-0.1
260-279	270.8	8	5.8	5.7	-0.1	14.0	15.0	1.0

Table 3.--Relation between minimum lethal concentrations of TFM as estimated from regression and as determined by bioassay

Method of estimation and range of TFM values (ppm)	Number of bioassays	Percentage in which bioassay result differed[1] from estimate by less than				
		0.5 ppm	1.0 ppm	1.5 ppm	2.0 ppm	3.0 ppm
Alkalinity						
0.5 - 1.4	15	87	100	...	...	...
1.5 - 1.9	21	76	95	100	...	...
2.0 - 2.4	30	57	87	93	100	...
2.5 - 2.9	27	63	85	100	...	...
3.0 - 3.4	33	45	76	91	100	...
3.5 - 3.9	17	47	65	88	94	100
4.0 - 4.4	23	39	61	74	96	100
4.5 - 5.4	17	35	65	82	94	100
5.5 - 6.4	10	20	40	70	80	100
Mean	...	53	77	90	97	100
Conductivity						
0.5 - 1.4	22	91	100	...	...	...
1.5 - 1.9	22	77	95	100	...	...
2.0 - 2.4	18	56	94	94	100	...
2.5 - 2.9	27	52	96	100	...	...
3.0 - 3.4	29	48	83	97	100	...
3.5 - 3.9	14	43	64	93	100	...
4.0 - 4.4	16	19	56	75	94	100
4.5 - 5.4	27	30	74	96	100	...
5.5 - 6.4	9	33	67	78	78	100
Mean	...	52	84	95	98	100
Alkalinity and conductivity[2]						
0.5 - 1.4	18	83	100	...	...	...
1.5 - 1.9	17	88	100	...	...	...
2.0 - 2.4	30	67	97	97	100	...
2.5 - 2.9	22	64	91	100	...	...
3.0 - 3.4	30	47	83	100	...	...
3.5 - 3.9	18	39	61	94	100	...
4.0 - 4.4	20	30	65	75	95	100
4.5 - 5.4	22	45	82	91	95	100
5.5 - 6.4	7	14	57	71	86	100
Mean	...	55	84	94	98	100

[1] In terms of absolute values of deviation from regression.
[2] Means of the two estimates.

Table 4.--Relation between maximum allowable concentrations of TFM as estimated from regression and as determined by bioassay

ethod of estimation and ange of TFM values (ppm)	Number of bioassays	Percentage in which bioassay result differed[1] from estimate by less than				
		1.0 ppm	2.0 ppm	3.0 ppm	4.0 ppm	6.0 ppm
lkalinity						
1.0 - 2.9	13	100	...	...	...	...
3.0 - 4.9	30	70	90	100	...	...
5.0 - 6.9	46	39	74	91	100	...
7.0 - 8.9	44	48	77	93	98	100
9.0 -10.9	32	38	69	84	94	97
11.0 -16.9	28	18	39	54	79	96
Mean	...	47	73	87	95	99
onductivity						
1.0 - 2.9	14	93	100	...	...	...
3.0 - 4.9	34	59	91	100	...	...
5.0 - 6.9	36	42	78	94	100	...
7.0 - 8.9	41	44	73	88	98	100
9.0 -10.9	28	36	57	71	86	96
11.0 -16.9	31	13	35	71	84	100
Mean	...	43	71	87	95	99
lkalinity and onductivity[2]						
1.0 - 2.9	13	92	100	...	...	...
3.0 - 4.9	29	72	93	100	...	...
5.0 - 6.9	41	49	80	95	100	...
7.0 - 8.9	38	45	82	97	97	100
9.0 -10.9	35	43	66	83	95	97
11.0 -16.9	28	18	50	64	86	100
Mean	...	49	77	90	96	99

[1] In terms of absolute values of deviation from regression.
[2] Means of the two estimates.

The situation is similar for estimates of maximum allowable concentrations of TFM except for the greater ranges of error (Table 4). Here, if probabilities in the range of 96-100 percent and averaging 99 percent are acceptable, it should not be necessary to extend tests beyond ± 6 ppm from the estimated concentration. At the lower estimated concentrations the testing ranges may be reduced to ± 2 ppm.

The mean of the estimates from alkalinity and conductivity is recommended as a basis for estimating the limiting concentrations. Neither alkalinity nor conductivity showed a consistent advantage over the other. Although the mean showed no advantage over estimates from conductivity alone for minimum lethal, it appeared superior to estimates from alkalinity, and to either single estimate on maximum allowable. More importantly, the mean is recommended as being the more dependable because each estimate will serve as a check against the other.

The estimates are in no sense substitutes for bioassays, but contribute to efficient planning of bioassays by indicating the limits over which tests need to be made and the concentrations near which close spacing of test concentrations is required.

Acknowledgments

I wish to thank Ralph Hile and Bernard R. Smith for their help in preparation of this manuscript, and the staff members of the Bureau of Commercial Fisheries at Marquette, Michigan, who assisted in accumulating the bioassay data.

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EXTRAIT

[redacted]

ICNAF Spec Pub No 4
1963
North Atlantic Fish
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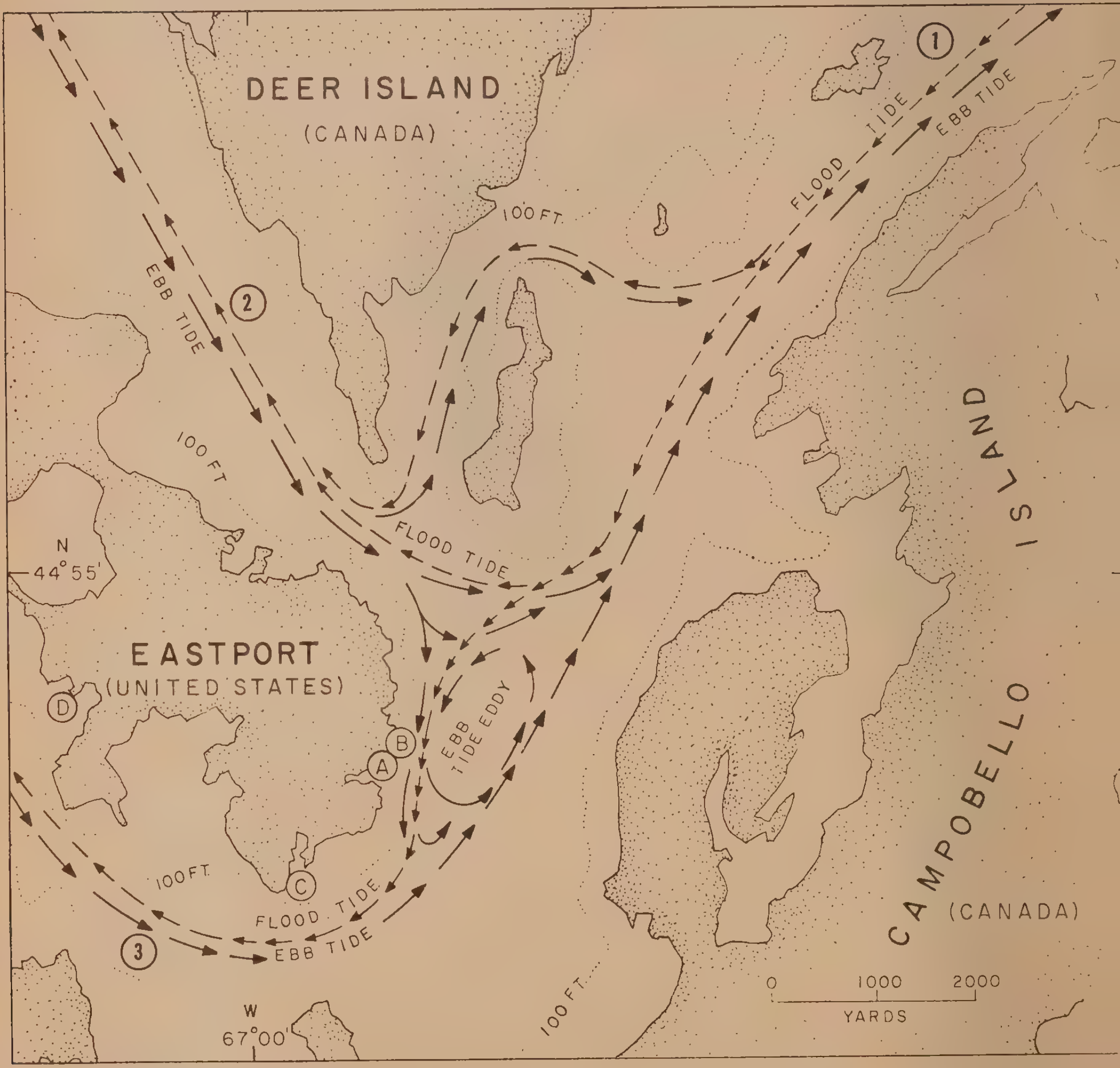
31.

Estimation of Population Size and Mortality Rates from Tagged Redfish, *Sebastes marinus* L., at Eastport, Maine

By

GEORGE F. KELLY and ALLAN M. BARKER*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FLOOD TIDE
EBB TIDE
③
W
67°00'
100 FT.
0
1000
2000
YARDS

Figure 1. Chart of Eastport vicinity showing tidal current pattern and location of four tagging sites, A, B, C and D. (1) Head Har Passage; 2) Western Passage; and 3) Cobscook Bay).

Introduction

Since 1956 more than 6,000 redfish have been tagged from an apparently isolated population that inhabits the waters around Eastport, Maine, near the mouth of Passamaquoddy Bay. This normally deep-water species comes to the surface around the d of the harbor and is caught readily on hook and while feeding during ebb tide at night.

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* U.S. Department of the Interior, Fish and Wildlife Ser Bureau of Commercial Fisheries Biological Laboratory, W Hole, Massachusetts, U.S.A.

Tagging was done at four locations in the area, nainly at two closely situated docks, points A and 3 in Figure 1. Fishing effort was sporadic during the ive years, regular neither in season nor in amount. The time of fishing was usually confined to the ortion of the monthly tidal cycle prior to the start f the spring tides. Large numbers of tagged fish vere recaptured in the tagging area by the investigaors; these were measured and returned to the water nharmed. Since there is neither a commercial fishery or redfish in that area, nor an active sport fishery for his species, the population is believed to have been irtually undisturbed during the study period except or the hook and line angling of the investigators.

Tag returns indicate that many of the fish remain n the area throughout the year (Kelly and Barker, 961). There is no evidence of migration from the agging area, since there were no returns from outside he immediate vicinity of tagging. Many of the fish lisplayed strong tendencies to remain in, or return o, particular territories, and a large number were epeatedly recaptured at the same location. The opulation is thought to be concentrated throughout he year in the comparatively deep waters of the ocky basin at the confluence of the tidal streams looding through Head Harbor passage and ebbing rom Cobscook Bay and Western Passage. Although here are no physical barriers to movement offshore, he population appears to be attracted here by a ombination of optimal year-round hydrographic onditions, seasonally supplemented with an abundance f euphausiid shrimp that are concentrated in the egion by the tidal currents, and are fed upon by he redfish. Many gravid females were caught in une and July. There appears to be little incentive or the fish to leave the area. The population appears o be in equilibrium, recruitment and other additive actors about equalling the annual depletive forces.

More than 2,400 tagged fish were recaptured from his physically unconfined, but isolated, population. Population estimates obtained from these data could e expected to be very precise, and to show a high legree of consistency, provided the proper assumptions vere used as the basis for the estimates. It is the purpose of this paper to present the estimates obained from different methods, and endeavor to letermine some of the factors contributing to the ariability of the results obtained at different times nd by different methods.

For the purpose of these studies, the following onditions were assumed to exist in the population:

1. natural mortality was the same for tagged and ntagged fish,
2. there was no loss of tags from the tagged fish,
3. tagged fish were as vulnerable to capture as ntagged fish,
4. tagged and untagged fish were randomly mixed in the population, and
5. a single population was available, and recruitment to the population and emigration from the area were negligible.

Results

As more tagged fish were added over the years, the proportion of tagged fish in the samples increased, reaching a peak in 1958 and diminishing in 1959 and 1960 (Fig. 2). After the first year, daily samples regularly contained between 60 and 85 percent tagged fish.

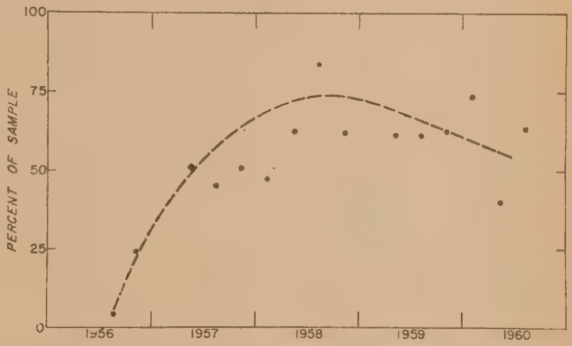


Figure 2. Changes in the proportion of tagged fish in samples, grouped in 3-month intervals, 1956 through 1960.

Estimates of population size were made using three accepted techniques; the Petersen, Schnabel and Schumacher-Eschmeyer methods. In each, all of the above assumptions must be satisfied to obtain an accurate population estimate. Each method gives an estimate of the total population size derived from the ratio of tagged to untagged fish in the samples. The equations for the methods are:

Petersen (1896)— $$P = \frac{AB}{C} \qquad (1)$$

Schnabel (1938)— $$P = \frac{\Sigma(AB)}{\Sigma C} \qquad (2)$$

Schumacher and Eschmeyer (1943)— $$P = \frac{\Sigma(AB^2)}{\Sigma BC} \qquad (3)$$

When: P = total population estimate
A = total number of fish caught during a unit time interval
B = total number of tagged fish released prior to sampling
C = number of recaptures in the sample.

Of the three techniques, the Schumacher-Eschmeyer method probably is best suited to the conditions that prevailed in this study. This approximation is considered most reliable when the ratio B/P is greater than 0.25 during most of the experiment, whereas the Schnabel method gives a less accurate estimate when this occurs. In the Eastport study, the ratio was greater than 0.25 for most of the time.

Early estimates were relatively high for each method, but as the number of recaptures increased the estimates steadily reduced. The values determin from the three methods are shown in Table 1. T Schnabel and Schumacher-Eschmeyer estimates a rather close and each has the same year-to-ye trend. The Petersen values are more variable th the other two.

A new method for population estimation w suggested by the repeated recapture of a great ma

Table 1

Population estimates of Eastport redfish computed by (1) Petersen, (2) Schnabel, and (3) Schumacher a Eschmeyer methods

	Petersen estimate[1]				Schnabel estimate[2]			Schu mach and Esch meye est.[3]
Date	A Total no. fish caught	B No. tagged fish available	C No. tagged fish caught	P Estimated population	B	C	P	P
1956								
September	1296	2106*	155	17609	2106	155	17609	17609
November	102	2106	25	8592	3231	25	16994	16731
September—November	1398	2106	180	16357				
1957								
May	20	3257	12	5428	3257	12	16271	15741
June	98	3257	48	6650	3257	48	14347	13382
July	644	3256	274	7653	3307	276	10800	9970
August	891	3256	397	7308	3489	428	9197	8626
October	100	3244	58	5593	3648	65	8966	8406
November	336	3244	136	8015	3676	162	8780	8285
December	135	3243	49	8935	3784	57	8789	8321
May—December	2224	3243**	974	7405				
1958								
February	28	3241	9	10083	3862	10	8791	8329
March	58	3241	27	6962	3879	30	8760	8306
May	128	3241	44	9428	3907	61	8735	8300
June	166	3241	104	5173	3974	125	8438	7997
July	361	3241	249	4699	4014	306	7795	7349
August	795	3240	519	4963	4014	694	6892	6495
September	85	3233	47	5847	4047	63	6856	6466
October	226	3230	94	7766	4069	141	6838	6469
February—October	1847	3230	1093	5453				
1959								
June	122	3224	54	7284	4069	75	6832	6474
July	315	3222	126	8055	4087	199	6807	6474
October	44	3089	26	5228	4101	36	6786	6454
December	35	3089	13	8317	4119	17	6795	6467
June—December	516	3089	219	7278				
1960								
February	100	3089	56	5516	4125	80	6753	6429
March	76	3080	30	7803	4134	49	6747	6429
April	103	3065	9	35077	4134	22	6834	6529
May	93	3059	33	8621	4134	51	6847	6547
July	117	3049	45	7927	4134	73	6842	6548
August	108	3049	45	7318	4134	78	6816	6527
September	66	3049	28	7187	4134	39	6818	6535
February—September	642	3049	246	8217				

[1] Using only fish released in 1956.

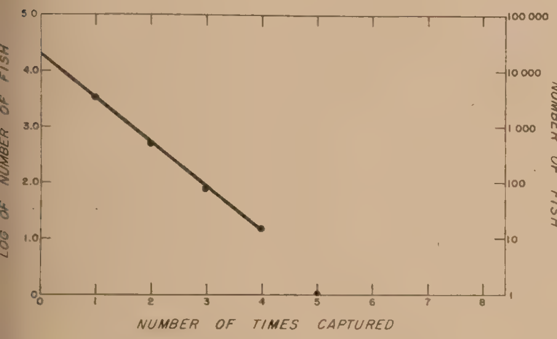
[2] Using all fish released prior to month of estimate.

[3] Based on same data used in computing Schnabel estimate.

* Released in July—August 1956.

** Minimum number available throughout the year.

sh, an unusual aspect of the present study. For this iethod to be successful, it is necessary that all re-aptured fish be returned to the water, and that all ntagged fish be tagged and set free. As operations ontinued, the number of one-, two- and three-time ecaptures reached substantial proportions, and some sh were recaptured as often as six and seven times. s these numbers increased, it became apparent that consistent relationship existed between the groups. t was noted that, where n equals the number of imes captured, the ratio n/n + 1 was approximately he same value between adjacent groups. A similar umerical relationship occurred between the two-



igure 3. Semi-logarithmic relationship between groups of edfish arranged according to the number of times captured. ased on the numbers of fish tagged in 1956 and recaptured in 1957.

nd three-time captures as was shown between the our- and five-time captures. When the numbers of ish were converted to logarithms and plotted against he number of times captured, the result was very early a straight line (Fig. 3). If this semi-logarithmic, traight-line relationship exists so strongly between andomly selected groups of fish that were captured ne, two, three or four times within a 1-year period, it is hen logical to extrapolate the curve to the y-axis to btain an estimate of the total population available. n Figure 3, a straight line fitted to the upper four oints intersects the y-axis at about 18,000, which s a slight over-estimate of the value that would esult from fitting the actual curve to all of the points.

The repeated recapture method appears to be free f sampling bias since the probability of catching ither an untagged fish, a first time recapture, or a nultiple recapture fish, is proportional to the relative bundance of each group in the population. The agged groups would be indistinguishable in the agged population except for the number of times ach had been captured previously. If the above listed ssumptions are met, the population estimate obtained y this method should fall very close to the actual opulation number.

The broad range of population estimates resulting from the four methods suggests that perhaps some estimates are too high while others are too low, and that the true population size probably lies somewhere between 6,000 and 20,000 fish. However, there is no evidence to support, with confidence, any particular value in preference over any of the others.

The wide variation in estimates also suggests the possibility that one or more of the stated assumptions regarding the population has not been met. Although there are no specific data to support the opinion, daily and seasonal variations in the ratio of tagged and untagged fish lead us to believe that the number of redfish in the waters surrounding the tagging area might be considerably higher than the number shown by the Schnabel and Schumacher-Eschmeyer estimates. Under the conditions of an open marine environment, it seems incredible that a mobile, apparently unrestricted population could be so limited in its distribution. It is suspected that some aspect of behavior, perhaps territorialism, accounts for the high incidence of recaptures and has resulted in population estimates that are too low.

Growth studies of the population indicate the probability that redfish tagged with the opercle tag suffer some malnutrition from reduced natural food supply, and, perhaps, are more likely to bite on a baited hook than untagged fish. If this is so, it would negate the third assumption of this study, and the improbable condition would prevail where tagged fish would be more vulnerable to capture than untagged fish. This would have opposite effects on the two types of population estimates used here. An increase in the rate of recapture would result in greater numbers of repeated recaptures. This would serve to raise the line fitted to the repeated-recapture data and would result in an over-estimate of the population size determined by this technique. On the other hand, for the standard methods, an increase in the recapture rate of tagged fish would result in an artificially high ratio of tagged to untagged fish, reducing the apparent number of untagged fish and resulting in an under-estimate of the population size.

There is insufficient evidence to question the applicability of the other assumptions used in the study. It is possible that other factors such as differential tagging mortality, or changes in the behavior of tagged fish, could alter the probability of recapture. If tagging mortality were a significant factor, it would tend to reduce the number of multiple recaptures, so causing an under-estimate of the population. If the fish became hook-shy, this would similarly reduce the probability of repeated recapture, with similar effect. The very fact that so many multiple recaptures have occurred suggests that this is not a major cause of error.

Mortality Estimates

Reduction in the percentage of 1956 tags present in the monthly samples of redfish was used to estimate the mortality rate of tagged redfish. More than 3,200 redfish were tagged during the period July through November 1956. Varying numbers of th
were recaptured in the samples collected each y
since that time. The monthly percentage incide
of this group of tagged fish is shown in Figure
Recaptures in 1956 were comparatively low, but
proportion reached as high as 69 percent in 1
(Table 2). The trend has been decreasing since th
A regression line was fitted to the sample data
1957—1960, giving equal weight to each of
monthly values of tag incidence. The slope of
line indicates a reduction from an average of 50.9 p
cent occurrence in mid-1957 to 40.2 percent in m
1960. If this line were extrapolated to 1 Decem
1956, the time at which all of the 3,257 fish tag
in 1956 were first available for recapture, the va
of the ratio would be 53.0 percent. When th
values are equated to percentage of the initial nu
ber of tags, there is an annual reduction of 6.7 perc
per year during the 4-year period.

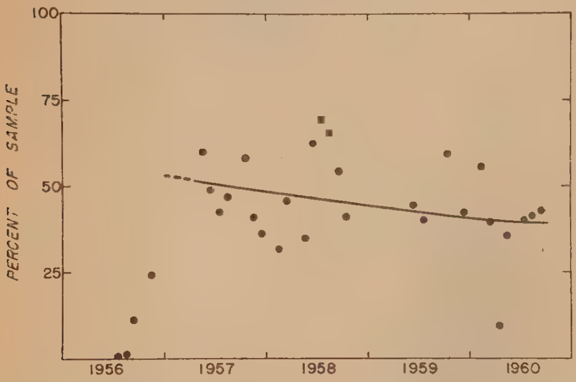


Figure 4. Changes in the monthly percentage incidence of fish tagged in 1956, recaptured during 1957 through 1960.

Table 2

Number and percent recaptured of redfish tagged at Eastport in 1956

		Total number caught	Number of 1956 tagging recaptured	Percent of sample tagged
1956 —	July	126	0	0.0
	August	1980	8	0.4
	Sept.	1296	155	12.0
	Nov.	102	25	24.5
1957 —	May	20	12	60.0
	June	98	48	49.0
	July	644	274	42.5
	August	891	397	44.6
	Oct.	100	58	58.0
	Nov.	336	136	40.9
	Dec.	135	49	36.3
1958 —	Feb.	28	9	32.2
	Mar.	58	27	46.6
	May	128	44	34.4
	June	166	104	62.7
	July	361	249	69.0
	August	795	519	66.5
	Sept.	85	47	54.1
	Oct.	226	94	41.6
1959 —	June	122	54	44.3
	July	315	126	40.0
	Oct.	44	26	59.1
	Dec.	35	13	37.1
1960 —	Feb.	100	56	56.0
	Mar.	76	30	39.5
	April	103	9	8.7
	May	93	33	35.5
	July	117	45	40.2
	Aug.	108	45	41.7
	Sept.	66	28	42.4

Aside from the previously mentioned behavio
factors that could influence the number of tag
fish recaptured, reduction in the percentage of tag
fish in the samples could be affected by the follow
factors: emigration of tagged fish, immigration
untagged fish, recruitment of young fish, differen
fishing mortality of tagged and untagged fish, tagg
mortality and natural mortality of tagged fish.
relatively high incidence of tagged fish through
the 4-year period suggests that emigration
immigration were of comparatively low magnitu
Since there is no evidence of tagging mortality, i
assumed to be negligible. In this study there was
measurable fishing mortality, because virtually
of the recaptured fish were returned to the wa
unharmed. The remaining causes of tag reduct
are recruitment of young fish and natural mortal

Recruitment of a slow-growing species is diffic
to measure, since it is spread over a longer time pe
than with faster-growing fish and does not appea
a seasonal influx of small fish that is readily discernibl
size composition measurements. During this st
there was no evidence of additions of small fish i
the population, and recruitment is assumed to h
been relatively low and of a gradual nature. Di
measurement of recruitment is therefore very diffic
However, if recruitment and immigration of untag
fish are equal to the natural mortality of untag
fish, then the change in the ratio of tagged: untag
fish is equal to the natural mortality. The comparati
low average reduction of 6.7 percent per year
maximum value, suggests that natural mortality
tagged redfish is of low magnitude.

It is not suggested that this measurement of nat
mortality should be considered as a probable morta
rate for the offshore redfish stocks. It is the va
obtained from an atypical population existing un

onditions that approximate to a modified aquarium xperiment. Many factors could prevail to influence is value in either direction. However, this value of .7 percent per year is a first approximation of atural mortality available for *Sebastes* anywhere, nd it may serve as a guide for population studies ntil more precise mortality estimates of exploited opulations are available.

Summary

More than 2,400 redfish were recaptured from a otal of 6,000 tagged since 1956 at Eastport, Maine. opulation estimates using three accepted estimation ethods indicate a population size between 6,500 and ,000 fish. A new estimation technique based on the epeated recapture of large numbers of fish indicates population of 18,000 fish. The difference in estimates is attributed to the unusual behavior of the Eastport redfish, resulting in unrealistically low population values using the standard estimation methods.

A mortality estimate based on the returns of fish released in 1956 indicates a natural mortality rate of 6.7 percent per year.

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ICNAF Spec Pub No 4
1963
North Atlantic Fish
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32.

Effect of Tagging on Redfish Growth Rate at Eastport, Maine

By

GEORGE F. KELLY and ALLAN M. BARKER*

Introduction

The occurrence of an inshore stock of redfish (*Sebastes marinus* L.) in shallow water at Eastport, Maine, has, for the first time, permitted extensive tagging of this species for growth and migration studies. Tagging began in 1956 and has continued to the present time. Initial results of the studies were reported in an earlier paper (Kelly and Barker, 1961) which reviewed the factors contributing to the unusual occurrence in shallow water of this deep-water fish, and summarized the observations on behavior, growth and migration through 1958.

In brief review, the redfish are present at Eastport throughout the year. They come to the surface at night, and are readily caught on hook and line as they feed on concentrations of the euphausiid shrimp *Meganyctiphanes norvegica*. A large number of the tagged fish have been recaptured in the vicinity of the tagging site, and many appear to display defensive territorial behavior and preference for particular locations. There is no evidence that these fish move to offshore fishing grounds at any time of the year.

During the first 3 years of tagging, 5419 fish were tagged with Petersen discs (Cons. Perm. Int. pour l'Explor. de la Mer, 1953) on the operculum. During 1959 and 1960, an additional 586 fish were tagged with modified yellow plastic spaghetti dart tags (Everhart and Rupp, 1960) applied in the flesh of the dorsum. More than 2000 of the Petersen disc-tagged fish have been recaptured; most of these were measured and returned to the water unharmed. Many have been recaptured two or more tim

This paper deals with the analysis of the recapt data from the Petersen disc tagging, the returns dart tags being insufficient for analysis at the pres time.

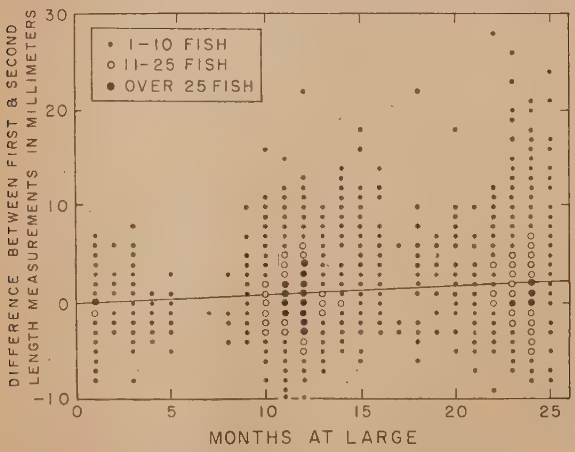

Figure 1. Measured growth of 2500 tagged redfish.

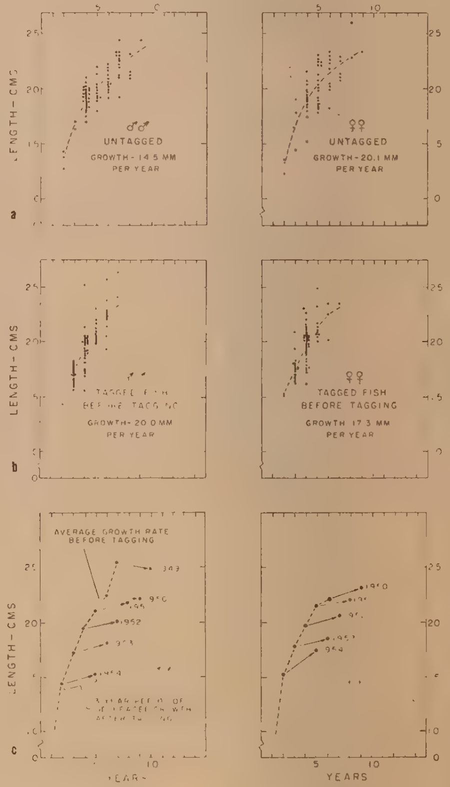

Figure 2. Comparison of growth rate of tagged and untag redfish. a. Growth of untagged fish determined from otoli b. Growth of tagged fish prior to the time of tagging, determi from otoliths. c. Growth of tagged fish determined from len measurements.

Results

Measurements of recaptured fish obtained early the study showed the growth of tagged fish to much slower than that determined from previ studies of Gulf of Maine redfish otoliths (Kelly a Wolf, 1959). A regression line fitted to the grow

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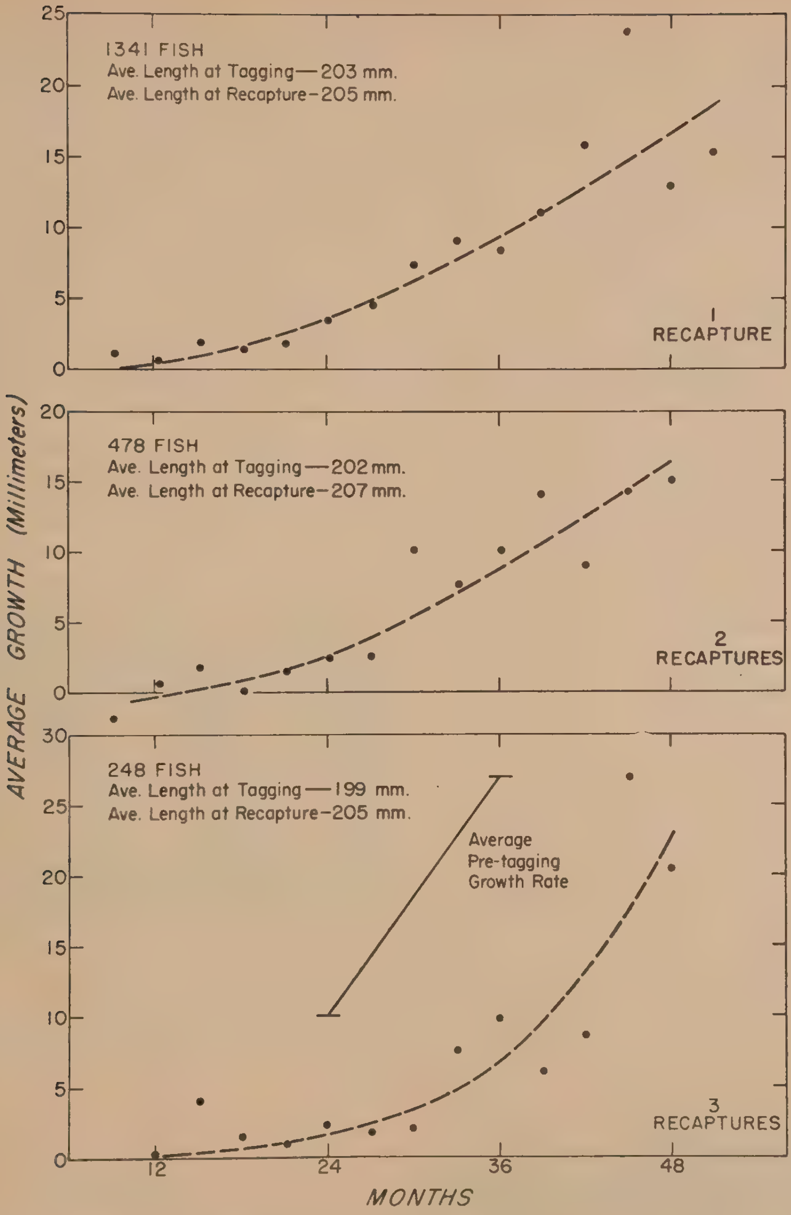

Figure 3. Comparison of changes in growth rate of tagged fish recaptured one, two and three times during a 4-year period.

ements of 2500 fish, measured over a 2-year od, showed an average increase of 1 mm per year ure 1).

camination of otoliths of tagged and untagged disclosed a consistent difference in the pattern of formation between the two groups. Otoliths untagged fish were similar to those of offshore of Maine redfish, the zone pattern consisting of a regular sequence of alternating opaque and hyaline zones. Otoliths of tagged fish contained a broad hyaline zone at the edge which was not present in the otoliths of untagged fish. The time of formation of the hyaline zone appeared to coincide with the time of tagging.

Growth rate determined from otoliths of untagged fish indicated an annual growth increment of 15 mm for males and 20 mm for females within the age range of 2 to 9 years, values close to those determined for offshore Gulf of Maine redfish (Figure 2).

Growth studies from otoliths of tagged redfish showed the growth rate prior to the time of tagging to be the same as the growth rate of untagged fish (Figure 3). Growth after tagging was very slow, the broad hyaline zone representing 2 or 3 years of diminished growth during which time the normal otolith pattern was disrupted (Figure 2).

While it was apparent that tagging influenced growth rate, it was impossible to state which aspect of the tagging operation was the primary cause. Since the tag did not physically interfere with the operation of the fish's mouth, and the tagged fish were readily caught on baited hooks, it appeared that they were behaving in a normal way. The decreased growth rate of apparently normal fish suggested that the psychological effect of tagging was a possible cause of diminished growth. A more probable cause, however, was judged to be the influence of the opercle tag in serving to startle live prey when the fish was feeding, frequently causing the prey to escape. The reduced intake of food resulting from this would, in turn, reduce the growth rate. Similarly, this would stimulate the hungry fish to bite readily on baited hooks, giving a false impression of normal behavior.

Additional recapture data have been collected since 1958, permitting further study of long-term influences of tagging on growth rate. The studies have had two aspects; first, the comparative effect of repeated recapture on the growth of fish recaptured once, twice and three times; and second, the duration of the slow growth period and the adjustment of the fish to the circumstances of tagging.

The average growth increments from measurements of fish recaptured one, two and three times during a 4-year period are summarized in Figure 3. In each group, growth was very slow for about $2^{1}/_{2}$ years. It then increased markedly in all groups, and, contrary to expectations, during the fourth year was greatest in the group that had been recaptured most freque While this may be an artifact caused by the relati small number of three-time-recaptures, the gro rate of this group has very nearly equaled the of growth of untagged fish. It is clearly shown tha growth rate of each group increased during the t and fourth year after tagging, and each has approa the growth rate of the pre-tagging period. comparison of otoliths of fish tagged for 1, 2, 3 4 years indicates that the hyaline zone at the ot edge has persisted for this entire period, increa gradually so that it is broadest in those at larg the longest time (Figure 4). In many otoliths of tagged for 3 or 4 years, thin traces of opaque mat are visible within the hyaline zone, suggesting a slow resumption of summer growth has occu in later years.

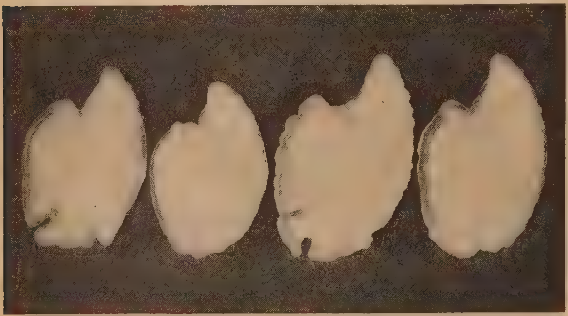

Figure 4. Comparison of otoliths of fish tagged 7 months, 2 years 3 years and 4 years

The comparison of otoliths of fish recaptured two or three times during periods of 3 or 4 years not show any discernible differences that could attributed to the effects of repeated recapture (ure 5). Otoliths from fish that had been recapt once during 4 years could not be separated object from those fish that were recaptured three tim 4 years.

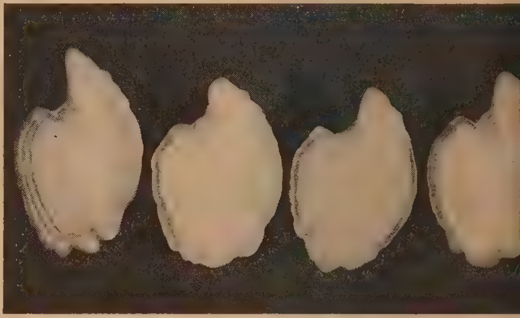

Figure 5. Comparison of otoliths of untagged fish and fish t for 4 years and recaptured one, two and three times

Discussion and Conclusions

The obvious effect of tagging was to inhibit gr of the fish for about $2^{1}/_{2}$ years, after which tim growth rate slowly increased. Additional han of the tagged fish during repeated recapture release in subsequent years did not appear to influ the rate of resumption of growth. These facts m possible a more precise determination of the prob cause of the initial cessation of growth.

Recaptured fish were handled in an almost iden manner to those caught for the first time. Each hooked, landed, held in a live car for several h measured and returned to the water. In addi new fish were tagged through the opercle, a ier minor operation since the pin was inserted ough the thin membranous portion. The two rations are so alike that it is illogical to name the as the cause of psychological shock without sidering the second operation the same. Since the ond operation did not affect growth, it is therefore sidered unlikely that either operation was sufficient- lamaging to cause the observed effect, and psycho- cal shock is discounted as the primary cause of reased growth rate of tagged fish.

lthough the opercle tag does not physically hinder fish, its role in diminishing the fish's food supply, startling live prey and causing it to escape, remains the most probable cause of diminished growth e. Apparently this influence changes in time, as lenced by the eventual resumption of growth. Of several possible contributing factors, fouling with rine growth is the most obvious occurrence that ld alter the effect of the tag. The fouled tag would less visible, and therefore less effective in arousing potential prey. Also, the fish may have adapted new conditions and learned to feed despite the sence of the tag. Either, or both, of these factors ld account for the sequence of changes in growth e.

agging mortality cannot be entirely discounted a possible explanation for the sequence of changes growth rate. If tagging mortality removed the wer-growing fish, those surviving to be recaptured uld display an ever-increasing growth rate as time sed and the number of recaptures mounted. How- r, there is little evidence of tagging mortality, since sickly or injured fish were recaptured during field rations. All of the recaptured fish appeared to be rmal and in healthy condition. Furthermore, the apture of as much as 40 percent of the tagged ulation, and the comparatively large number of repeated recaptures, serves to minimize the probability of tagging mortality as a major factor influencing the apparent growth rate of the tagged fish.

Summary

An initial decrease in growth rate occurred when redfish were tagged with opercle tags. Otoliths of tagged fish showed a zone of hyaline material at the edge that was not present in the otoliths of untagged fish. After $2^1/_2$ years of diminished growth, the growth rate gradually increased toward the pre-tagging value. Fish that were caught and released three different times appeared to grow as fast as those recaptured only once. The sequence of growth changes might be explained as the effect of the opercle tag causing the escape of potential prey, thus reducing the food supply and decreasing the growth rate of the fish. The eventual resumption of growth is probably the result of increased food intake caused by a combination of two factors, the tag becoming less visible because of fouling with marine organisms, and the fish learning to feed in spite of the presence of the tag.

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Made in United States of America
Reprinted from Journal of Mammalogy
Vol. 44, No. 2, 20 May 1963
pp. 280–282

AGE DETERMINATION IN THE HAWAIIAN MONK SEAL

Karl W. Kenyon and Clifford H. Fiscus

AGE DETERMINATION IN THE HAWAIIAN MONK SEAL

The Hawaiian monk seal (*Monachus schauinslandi*) is scarce. Its range is limited to a few islands in the Leeward Hawaiian group. Few specimens have been collected. Life history observations have recently been published (Kenyon and Rice, 1959; Rice, 1960) but much is still to be learned of its biology. The monk seal lives in a uniform climate. Its breeding range lies between 23°30′ and 28°30′ N lat. Annual variations in light intensity and length of daylight are less than in the environment of most pinnipeds. At Midway Atoll the monthly mean air and water temperatures vary from about 66° F in winter to 78° F in summer. The monk seal is nonmigratory.

Studies of the teeth of pinnipeds have revealed annular layers which may be used as an indication of age (Scheffer, 1950; Laws, 1952). The species already studied are in polar or subpolar climates having well-defined seasons. The life histories of these animals exhibit, in most cases, an annual range of rather distinct phases. Annuli or ridges, are distinct on the outer surface of the teeth of the following seals (at least): *Callorhinus* (Scheffer, 1950), *Eumetopias* (Fiscus, *in litt.*), *Zalophus, Odobenus* (Mansfield, 1958) and *Mirounga* (Laws, 1953).

It has been suggested that the deposition of annular layers in the teeth may be a response to alternate periods of feeding and fasting, to variations in available food in different places visited during the year and to seasonal variations in length of day or intensity of light. Thus, it is of interest to examine the tooth structure of the monk seal, a sedentary subtropical species.

The upper right canine teeth from an adult male (specimen BDM 490) and a female (BDM 489) killed at Midway Atoll in the winter of 1958 were examined externally and then cut and polished to reveal the central longitudinal plane, using a technique described by Fisher and Mackenzie (1954). The external surfaces did not show annuli. In the teeth of both specimens, the pulp canal was completely closed and the dentin showed annular layers. The growing tip (apex) was surrounded by distinct layers of cementum. The whole cementum layer is thick, to 7 mm in the male and to 3 mm in the female. The layers do not decrease in thickness with age, which is also the case in the ringed seal (*Phoca hispida*) (McLaren, 1958).

Annular layers in the dentin are used for age determination in *Callorhinus* and *Eumetopias*, although in *Eumetopias* age readings may be obtained from the cementum in older animals. Lines are also visible in the cementum of *Callorhinus* but this layer is so thin that reliable age readings from it are seldom obtainable. In phocids that have been studied the cementum is thicker than in otariids. McLaren (1958), in his study of the ringed seal, found that there is a one-to-one correlation between the dense cementum and dentin bands. Mansfield and Fisher (1960) have shown that annular bands in the cementum indicate age in the harbor seal (*Phoca vitulina*). Hewer (1960), studying annular layers in the cementum of the grey seal (*Halichoerus grypus*), points out the need for caution and further study in applying this method of age determination when critical determinations of the exact birth season are necessary.

By analogy with the foregoing it may be concluded that in the subtropical Hawaiian monk seal fasting, probably during molt, causes visible annular interruptions in the deposition of cementum and dentin which may be used as an indication of age. In the specimens studied, the pulp canal of the canines appeared to have filled completely at the relatively early age of about 4 or 5 years as indicated by visible layers in the dentin. The root of the teeth continued to grow in girth and length throughout life by the deposition of cementum. Dense bands in the cementum indicate an age for the male of about 20 years and for the female of about 11 years. The worn teeth of the male and moderate wear in the female tend to confirm in a general way the age readings obtained. —Karl W. Kenyon and Clifford H. Fiscus, *U. S. Fish and Wildlife Service, Seattle.* *Received 16 April 1962.*

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nce of heartworm. Rectal examination ed an elevated mass on the lateral al rectal wall about 2 in. from the This mass had a rough surface and about the size of a half-dollar.

A biopsy was taken and analyzed by a logist at the local hospital. The re- tated that the rectal wall, containing normal and abnormal mucosa, had gone extensive invasion by linear p of rounded cells. Pathological diag- was extensive adenocarcinoma with sion of other tissues.

Euthanasia was performed.

Stephen [illegible], D.V.M.
[illegible]

Rheumatic Fever in a Gorilla

THE OPERATOR of a children's zoo called advice concerning a 14-month-old lla. He reported that for 3 months after heat had been shut off in its trailer, the lla had suffered intermittent swelling of joints.

Tentative diagnosis was rheumatic er. The EKG was normal except that e P-wave was inverted. C. reactive pro- n 40; sedimentation rate less than 10 nutes.

Following consultation with a pedia- cian and an M.D., the gorilla was given r of sodium salicylate *t.i.d.* and Alba- cin (Upjohn).

The swelling diminished and the ani- al was moved by its owners to winter uarters in Florida.

M. A., D.V.M.
New Jersey

Necrotic Hemorrhagic Enteritis in a Seal

OUR LABORATORY PERSONNEL supplied the land Park Zoo with a young male and g female northern fur-seal (*Callor- ursinus*) from the Pribilof Islands.

The male adapted quickly to captivity, ate adequately and remained in good health. However, the female died suddenly after a period of anorexia.

The cause of death was tentatively diagnosed as enterotoxemia caused by clostridial infection of the small intestine. Necropsy revealed the primary lesion to be necrotic hemorrhagic enteritis.

Bacteriologic examination (at the State Agriculture Laboratory, Olympia, Wash.) isolated *Clostridium perfringens* in pure culture from a loop of affected intestine.

Mark C. Keyes, D.V.M.
Marine Mammal Biological Laboratory
Seattle, Washington

Feline Enteritis Resembles Intestinal Obstruction

AN ADVANCED CASE of feline enteritis was presented with symptoms resembling an intestinal obstruction. The terminal condition of the cat precluded successful treatment.

The patient, a 3-year-old female cat, had disappeared for a week, and on return home, appeared anemic, weak and listless and could retain no solid food.

Although an intestinal obstruction was suspected, radiographs were not taken because the cat was obviously in a terminal condition. Fluid therapy and blood transfusions were started but the cat died within 4 hours.

The interesting feature of this case was the appearance of the intestines at necropsy. The lymph glands at the ileocecal junction completely closed the intestinal passageway. The intestines were bloodless and thickened. Samples of the lymph glands and intestine were sent to the pathologist.

With a diagnosis of panleucopenia, the pathologist's report stated that the intestinal tract had marked mucinous degeneration in some parts and in other parts the epithelium appeared to be practically denuded - the little epithelium that remained carried large intranuclear inclusion bodies.

Allen S. Neyle, D.V.M.
Wayne, N. J.

Made in United States of America
Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 92, No. 3, July, 1963
p. 323

OPICAL INLAND FISHERIES. *By C. F. Hickling. (Tropical Agriculture Series.) John Wiley & Sons, Inc., New York. 1961. 287 pp., 4 figs., 68 plates (part col.), 13 tables. $7.25.*

The British Colonial Office had in the recent past e most extensive obligations for tropical inland hery research and administration of any organiza- n in the world. Dr. Hickling, as Fisheries Advisor this office and as Acting Director of the Fish lture Research Station at Malacca in the Fed- ation of Malaya, was in a unique position to make rsonal observations and have access to information the widest variety of tropical inland fisheries. He , therefore, eminently qualified to author an intro- ction to, and a survey of, his subject.

The book is organized around four general topics, y one of which could be the theme of a volume. e passes from an introduction to tropical limnology a discussion of the biology of tropical fisheries, ence to a brief survey of fishing methods, preser- ation, and marketing, and finally to an extensive iscussion of various natural as well as artificial land tropical fisheries.

This book should be required reading for any tem- erate-zone, freshwater fishery biologist venturing nto the tropics as an expert or advisor in one of the arious aid programs. There has been a considerable mount of lost and ineffectual effort on the part of ome of these people due primarily to their lack of ven a rudimentary knowledge of tropical fishery iology or so-called primitive fishing methods.

A method in which a man stands in a muddy tream and randomly tosses a spear into the water n hopes of hitting a fish may be said to be primitive. n this instance, the introduction of more sophisti- ated methods would appear to be profitable. On he other hand, this same individual may take part in highly organized fishery consisting of a complex eries of weirs and associated traps of enormous pro- ortions and high efficiency. This fishery would be onsidered primitive only in the sense of location sometimes a bit of snobbery here) and materials sed. So-called primitive fishing methods can be highly productive and, what is more, well suited to the fishery and the people involved. They may be so productive that ill-advised, restrictive regulations predicated upon temperate-zone sport fish experience may be arbitrarily applied. The assumption, usually with little or no experimental evidence, is made that if large numbers of fish of all sizes are being taken, then the method is likely to be harmful. The extra-ordinary recuperative power of most tropical fisheries is not understood or considered. Dr. Hickling tells of a report made in 1878 on the future of a particular fishery in which the prediction of overfishing was made if a particular weir system continued in use. Apparently nothing was done; the method is still in use, and the fishery remains as productive as ever.

Dr. Hickling does not imply that modern or temperate-zone methods are not applicable in the tropics. He is suggesting that regulatory or management assumptions made on the basis of nontropical experience need some investigation and evaluation in the light of tropical needs and biology before they are applied.

A good example of the wise use of new techniques was the introduction of nylon gill nets into the freshwater fisheries of Uganda by the Colonial Office Fishery Officers of the Uganda Game and Fisheries Department. The high efficiency of these nets led to economic conditions favorable for the development of an outboard-motor-powered fishing fleet. A subsequent refinement was the building of access roads and marketing centers to facilitate movement of the product into areas of demand. All this was done in such a manner that no undue dislocation of people or of fisheries occurred. In all fairness, however, it must be said that not everyone conversant with the fisheries of Uganda believed the innovations to have been beneficial. It has, however, yet to be proved otherwise.

The first thought regarding the section, *Lake and Dam Stocking; Fish Transplantation*, is that it is too short. There is much more that can be said regarding this important aspect of fisheries development. A single paragraph is allotted to Southern Rhodesia where more than 8,000 artificial ponds exist, most of which have been stocked with fish. There is also no mention of the important pond culture work done in Southern Rhodesia by Dr. A. Marr at the Fisheries Research Center near Mazoe. Kenya and Uganda share a somewhat longer paragraph. Both of these countries have pond culture schemes. Uganda has an excellent pond culture research center at Kajansi from which considerable information has been obtained. One Uganda province in 1958 had over 1,000 farm ponds stocked with *Tilapia*. An interesting point to be gained from this chapter is that the successful pond schemes utilize fish that are either native to the country or of tropical origin.

Dr. Hickling, in what may be unconscious agreement with other fishery experts, believes much of the future development of tropical inland fisheries lies in the direction of fish (pond) culture and the judicious stocking of new species. There is much to be said in favor of pursuing the former course and much more to be said in favor of going slow on the latter. We are only in the first stages of knowledge concerning the ecology of natural tropical fisheries. Fishery workers in the newly emerging states of the tropics are faced with ever-increasing demands for fishery products with the result that fishery development is often ahead of its supporting research. This book is not a substitute for research, but its use by harried fishery men in these countries should materially increase the number of better decisions, as they will be based on tropical rather than temperate-zone experience.

The author remarks that, "What is wanted is faith, by those who hold the public's purse, in the value of fisheries research. . . ." One does not need to be working in inland tropical fisheries to agree with this view.

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REVIEWS

BETWEEN PACIFIC TIDES. *By Edward F. Ricketts and Jack Calvin. Third edition revised by Joel W. Hedgpeth. Stanford University Press, Stanford, California. 1962. 516 pp. $8.75*

This book has been a necessity for Pacific Coast marine biologists and students since its first appearance in 1939. The 1962 revision of the *Third Edition* (1952) maintains the high quality of the original as well as offering some pertinent new material.

The first four chapters remain virtually unchanged except for a number of new illustrations, all of which were improvements. The organization of these chapters is similar, and each treats a broad shore habitat classification; *i.e., Protected Outer Coast, Open Coast, Bay and Estuary,* and *Wharf Piling.* Each of these habitats are, in turn, divided into four zones or horizons based on tidal exposures, ranging from the infrequently wetted uppermost beach to the low-tide region normally uncovered only by minus tides. Where advisable, the zones are subdivided into smaller units such as "Under-rock" or "Exposed rock." The animals in each of these zones and subzones are described, and something of their life history is given. The result is not a dry series of listings but rather a series of scientific vignettes and anecdotes.

This book has developed into something of a memorial to Ed Ricketts, the most apparent manifestation being the unchanged *Foreword* and *Preface.* The continuation of the policy in the *Third Edition* (revised) is noted in the new lead illustration for the chapter on *Wharf Piling,* where a much more interesting and appropriate photograph of Cabrillo Point (includes Cannery Row) replaces a nondescript view of Point Conception.

The introduction to Chapter V, *Intertidal Zonation and Related Matters,* has been brought up to date, although the remainder of the discussion has been changed little. A new chapter, *Newcomers to the Pacific Coast,* has been added. It formerly was something of an afterthought in the *Intertidal Zonation* section.

The greatest change in the text has been made in former Chapter V, *Plankton.* It has been eliminated. In its place has been added a new and interesting Chapter VII, *Beyond the Tides: The Uncertain Sea.* It is essentially an introduction to offshore marine ecology, drawing for much of its material on reports of the California Cooperative Oceanic Fisheries Investigations (CalCOFI). It ranges widely over problems in marine ecology of common knowledge to Pacific Coast people. Utilized as points of departure for discussion are such things as the disappearance of the Pacific sardine, the sewage outfall problems of southern California, and the disposal of radioactive wastes in the marine environment. Dr. Hedgpeth does quite well, and knowing his concern for the future regarding pollution by nuclear reactors using the ocean as a cooling source, I think he shows remarkable restraint in his discussion of that subject.

One more or less recurrent criticism of this book in all its editions and revisions has been the quality of the line drawings and graphs. This poor quality has been carefully maintained in this revision. I say carefully because the new chapter, *Beyond the Tides,* has a number of graphs most of which were taken from CalCOFI reports and duly acknowledged. However, instead of using the well-drawn graphs directly or maintaining their original high quality, each has been redrawn so that it matches the poor quality of graphs and diagrams in the previous editions. The inclusion of one particular illustration (Figure 132) serves no need. The photographs, by and large, are excellent, although there is a consistent tendency for them to be printed too dark.

Through all the editions and revisions, the appendix with its annotated systemic index and bibliography has remained one of the most valuable portions of the book, and if not complete, it is certainly adequate. It has also been updated.

Ricketts, and I suppose Calvin as well (although we know little about him), apparently thoroughly enjoyed studying the ecology of the seashore and wanted other people to appreciate and share their enthusiasm. Their interest is effectively furthered by avoiding the highly specialized terminology that has become associated with the study of communities. They have maintained instead a natural straightforward style, using sophisticated but intelligible language and employing special terms as needed but not as studied symbols of their erudition. Dr. Hedgpeth, insofar as is possible, maintains this style in his revision.

The comments regarding illustrations notwithstanding, this book, in my opinion, still remains the best of its kind for the Pacific Coast from northern Baja California, to southeastern Alaska. Perhaps the 1972 edition will do something about the line drawings.

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~~LABORATORY ESSENTIALS OF PARASITOLOGY. *By Marvin C. Meyer and Lawrence R. Penner. Revised edition. W. C. Brown Company, Dubuque, Iowa. 1962. 134 pp.*~~

~~The aim of the authors was to prepare a laboratory manual "to meet the needs . . . of any student taking his first course in general animal parasitology." The manual was to include not only the common parasites of direct human concern, but also those of other animals; instruction for the preparation of material prior to examination under the compound microscope was to be included. In all of the above, the authors have met with outstanding success.~~

~~The manual is not entirely free of errors, but the errors are few and are those commonly found in textbooks. For example, the authors state (p. 3) that the Trematoda have an incomplete alimentary canal. This is true in most cases, but certain members of the family Allocreadiidae, for example, have a complete alimentary canal.~~

~~This revision is well written and almost free from typographical errors. Several manuals (Cable, R. M., *An Illustrated Laboratory Manual of Parasitology;* Hoffman, G. L., *Medical Parasitology;* Manter, H. W., *A Laboratory Manual in Animal Parasitology*) give special reference to the animal parasites of man. These manuals all contain one feature, a~~

Reprint from Transactions of the American Fisheries Society,
vol. 92, no. 1, p. 69, January 1963.

Int. Arch. Allergy *23:* 246–253 (1963).

Immunoelectrophoretic Studies of Red Salmon *(Oncorhynchus nerka)* Serum

By Kathryn K. Krauel and George J. Ridgway

Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Washington

In previous studies conducted in this laboratory (7), it was found that blood samples taken from individual red salmon differed in their antigenic constitution when tested by the immunodiffusion method of Ouchterlony (6) with immune antisera prepared in rabbits.

It was also found that maturing female salmon possess a complex antigen in their serum which is not detectable in the sera of males and immature females. This character was generally present in females with gonads greater than 10 grams in weight, and was also present in high concentration in the eggs. This component is called Sm antigen.

In order to obtain a better understanding of the nature and properties of the antigenic components of salmon serum, especially those varying between individuals, and to increase the precision of the test for them, the present study was conducted using the method of immunoelectrophoresis. Scheidegger's (8) micro method of immunoelectrophoresis was modified to suit the needs of our study. In this paper, we shall describe the method as we have adapted it for use in studying the antigenic components of salmon serum and present some preliminary findings concerning the nature and occurrence of these components.

Methods

A Spince Model R Paper Electrophoresis apparatus was used. The three inches from one filter paper wick support to the other were adequate for the microscope slides used to support the agar gel medium. We found it most convenient to use slides two inches

wide so that two samples could be placed on one slide with room for proper antiserum troughs to be cut in the agar and still leave ample space for diffusion.

The slides were coated with 2–3 ml. of a ½% solution of Noble agar and dried overnight in an incubator, and then 5 ml. of 2% Noble agar with "merthiolate" preservative in barbiturate buffer (mu = 0.025, pH = 8.5) were placed evenly on each slide. After standing overnight in a moist chamber, two small round wells of 2.4 mm. diameter were punched in each slide with a die using a template to assure uniform positioning. The slides were supported in the paper electrophoresis apparatus on a cooling plate through which ice water was circulated. Connection to the filter paper wicks in the anode and cathode basins was made by means of Whatman No 3MM filter paper wicks, 1½ inches wide. One thousand ml. of barbiturate buffer (5.15 g. sodium barbital, 1.25 g. barbital per liter, mu = 0.025) were used in the buffer compartment of the apparatus. The buffer composition in the chamber was the same as that on the slides, but without the agar. Five slides could be run at the same time with a total constant current of 45ma. An equilibration period of 30 minutes was routinely used, after which the wells were filled with the test serum. The length of the run was varied to determine optimal time, and this proved to be one hour with cooled slides.

Early experiments indicated that the best position for the sample wells was in the center because displacement from the central position usually resulted in some components diffusing off the end of the slide.

Variation of the pH of the barbiturate buffer from 8.3 to 8.6 seemed to have little effect. Tris buffer of pH 7.4 and phosphate buffer of pH 7.4 were also tried. The resolution obtained with tris buffer was uniformly inferior to that with either of the other buffers. The phosphate buffer gave sharper precipitation arcs upon subsequent addition of antiserum than the barbiturate buffer in some cases, but the effect was inconstant. Occasionally arcs were apparent with the barbiturate buffer which were not apparent with the phosphate buffer, whereas the reverse was never true.

Immediately after completion of the electrophoresis, troughs 5.75 cm. long by 2 mm. wide were cut in the agar with a two-bladed cutter and a template. The troughs were then filled with antiserum. Lyophilized antiserum reconstituted to $^1/_3$ the original volume, or three applications at half hour intervals of unconcentrated antiserum was used.

Diffusion took place in a refrigerator in a moist chamber for the next five days, and washing of the slides was started on the fifth day. Precipitation arcs were usually present after 24 hours, but better arcs resulted from the longer diffusion period.

Unprecipitated protein was removed by washing the slides with 0.9% sodium chloride solution for three and a half days. During this process, the slides were constantly covered with bibulous paper for protection of the agar mat. The saline wash water was changed three times a day and between each change the slides were blotted with bibulous paper. Finally they were blotted with several changes of bibulous paper partially dried in air and soaked in three changes of distilled water to remove any traces of salt.

The slides were dried overnight at 37°C and stained with a solution of 100 mg.% Buffalo Black in 5:5:1 methanol:water:acetic acid for ten minutes, blotted and washed for ten minutes in 10:5:1 methanol:water:acetic acid. After rinsing with water and drying in the incubator, clear blue arcs of protein precipitate were present on a virtually colorless background.

In some cases, slides were stained for three hours with a saturated solution of Azocarmine B in 5:5:0.3 methanol:water:acetic acid. No noticeable differences in the number of the lines were found when the results with the two stains were compared.

In order to study lipoproteins, a few slides were stained with Oil Red 0 which had been purified according to the method of KUTT AND TSALTAS (5) by extracting ten times in 60% ethanol.

The antisera used in the studies reported here were produced in rabbits by multiple stimulation with salmon serum, washed hemolyzed salmon erythrocytes, Sm antigen or human serum incorporated in Freund's adjuvant. A few experiments were run using goat antisera produced in the same way. These antisera also gave excellent resolution.

Results

Comparison of human serum with salmon serum by immunoelectrophoresis (fig. 1) indicated that the albumins migrate nearly identically. With the rabbit anti-salmon serum used in these studies components migrating as pre-albumins and gamma globulins were less apparent than in human serum developed against anti-human

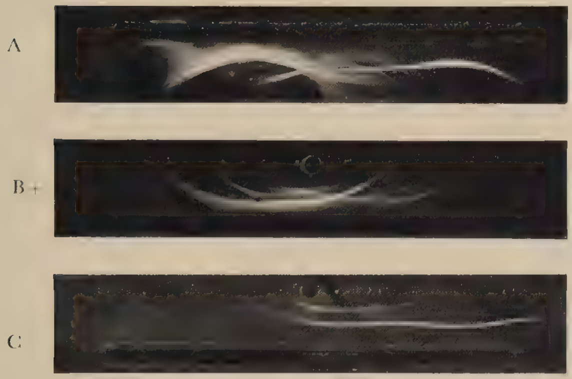

Fig. 1. Immunoelectrophoretic pattern of human serum developed against rabbit anti-human serum (A) compared with that of red salmon serum developed against rabbit anti-red salmon serum (B) and red salmon serum developed against rabbit anti-red salmon washed hemolyzed erythrocyte serum (C). Electrophoretic heterogeneity is shown in both beta and gamma globulin constituents in C.

rabbit serum. Human gamma globulin ran off the cathode end of the slide in one hour in our method, whereas salmon serum constituents rarely approached the end of the slide during one hour.

Fifty red salmon sera were analyzed in duplicate on separate slides and at different times. Duplicates were nearly identical when the two slides were superimposed. The results of these studies are summarized in table I.

The positions of the components were determined by measuring the distance of the center of each arc from the origin. Taking the origin as 0, this distance was expressed in millimeters as + if the reading was on the anode side of the origin and as — if the component had diffused to the cathode side of the origin by electroosmosis. The designations given the various components in salmon serum were based on comparisons with the mobility of human serum components.

The albumin arc was broad and well marked in all of these sera. Measuring the location of the center of the arc in millimeters distance from the origin, 4 were +10 mm., 5 were +9 mm., 28 were +8 mm., 11 were +7 mm., and 2 were +6 mm.

All arcs whose centers were to the anode side of the center of the albumin arc were considered to be pre-albumins. All arcs with centers between the albumin arc and +4 mm. from the origin were

Table I

Variation in antigenic components in sockeye salmon sera demonstrated by immunoelectrophoresis.

Component categories	Number of components in each category	Number of individuals possessing a given number of components
Pre-albumins	0	25
	1	22
	2	3
Albumins	1	50
Alpha-1 globulins	0	6
	1	15
	2	17
	3	10
	4	2
Alpha-2 globulins	1	14
	2	11
	3	13
	4	7
	5	3
	6	2
Single-arced beta globulins	1	2
	2	31
	3	12
	4	4
	5	1
Double-arced beta globulins	0	7
	1	2
	2	30
	3	10
	4	1
Single-arced gamma globulins	1	46
	2	4
Double-arced gamma globulins	0	48
	1	2

considered to be alpha-1 globulins, while those with centers from +3 to 0 mm. were called alpha-2 globulins.

In addition to the broad albumin arc, a second major component, which occurs very close to the origin in the alpha-2 globulin region, is apparent in all of the sera tested. The center of the arc due to this component occurs from +4 to 0 mm. from the origin.

Beta globulins were measured from —1 to —14 mm. and gamma globulins were those from —15 to —27 mm. Serological cross-reactivity was shown in some cases in which the slower moving portion of a double arc lay in the beta or gamma globulin region, whereas the faster moving section overlapped the alpha or beta globulin region. The more mobile components in these double arcs were considered to be "fast" beta globulins or "fast" gamma globulins (fig. 1).

Most of our pooled rabbit anti-red salmon sera detected gamma globulin very poorly, but a special antiserum developed against, washed hemolyzed salmon erythrocytes indicated the presence of at least one gamma globulin component in each red salmon serum tested.

It is apparent from the data in table I that considerable polymorphism in the components of red salmon sera is detected by immunoelectrophoresis. As many as 25 components could be detected although no individual serum was found which possessed all of them. The slower component in some of the double arcs is probably identical with some of the single arcs, but the latter did not show the faster moving cross-reactive constituent. The fact that duplicate runs are so nearly identical indicates that there is a real polymorphism present in the sera, however it is possible that some of this variation is due to quantitative rather than qualitative differences. Further experiments are in progress to elucidate this point.

Ten experiments were conducted on the female maturity (Sm) factor (7) in which mature male and mature female red salmon were compared. A partially purified Sm antigen was prepared by precipitation at low ionic strength. Antiserum prepared by immunization with this antigen was used in the center trough and anti-male red salmon serum was placed in the two outer troughs. The results are shown in figure 2.

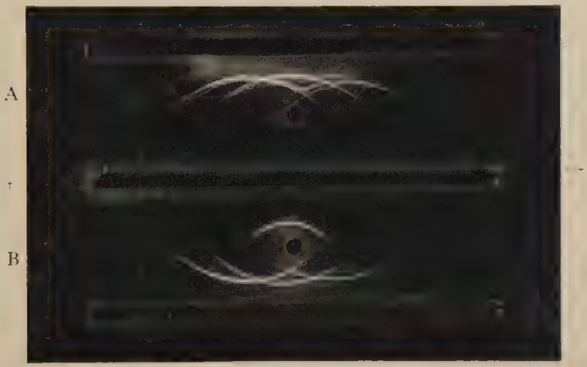

Fig. 2. Immunoelectrophoretic pattern of mature male red salmon serum (A) and of mature female red salmon serum (B). The antiserum in the center trough was prepared using a partially purified Sm antigen from red salmon eggs. The antiserum in the outer troughs was prepared with mature male red salmon serum.

The Sm factor migrated as a single constituent. Its migration just balanced the endoosmotic flow so that the precipitate always occurred directly opposite the sample well. This places the Sm factor with the alpha-2 globulins in electrophoretic mobility. The Sm precipitin arc was never found with male salmon serum, but always occurred with mature female salmon serum. It stained readily with purified Oil Red 0 which indicates that it is a lipoprotein.

Discussion

The number of components demonstrable by immunoelectrophoresis is of course dependent upon the number of specific types of sufficiently potent antibodies that are present in the antiserum used. In their original studies, WILLIAMS AND GRABAR (11) demonstrated 16 distinct antigens in human serum using immunoelectrophoresis. WADSWORTH AND HANSON (10) found 21 antigens in bovine serum and HIRSCHFELD (4) and others found as many as 24 different precipitin arcs in human serum. We found evidence for as many as 25 antigens in salmon serum, but no more than 18 have been found in any individual.

Previous immunoelectrophoretic studies of fish sera include those of FINE AND DRILHON (2), who studied eel serum, and those of BARGETZI (1), who demonstrated differences between the sera of two forms of whitefish.

Of particular interest in our studies are the cross-reactive double arcs in the beta and gamma globulins and the apparent polymorphism in the pre-albumin and various globulin fractions.

The antigen we call Sm may be identical with the "serum vitellin" reported by VANSTONE AND HO (9). Immunoelectrophoretically, this component lies in what we have called the alpha-2 globulin area, and since we have also demonstrated the presence of lipid, it may be assumed to be a lipoprotein complex with the mobility of an alpha-2 globulin in agar. Other evidence obtained in this laboratory indicates that it has the mobility of a beta-globulin in paper electrophoresis.

Although our studies of these individual variations have not been completed and we have no evidence bearing on the genetic control of these characters, the fact that these differences are consistent and repeatable indicates that they are significant. We are continuing these studies and hope to obtain evidence bearing on the possible genetic control of these components and their correlation with geographic origin.

Summary

A modification of the micro-immunoelectrophoresis method of SCHEIDEGGER using the Spinco Model R Paper Electrophoresis apparatus with water-cooled slides is described.

The mobilities of antigens present in red salmon sera are compared with the mobilities of those in human sera. Pre-albumins and gamma globulins, although present, are less apparent in salmon than in human serum. Albumin, alpha-1, alpha-2 and beta globulins are well represented.

A comparison is made of the antigens present in 50 red salmon sera. Evidence is presented for polymorphism in pre-albumin and globulin components.

A lipoprotein antigen present only in mature female salmon is shown to migrate as an alpha-2 globulin in agar.

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 92, No. 2, April, 1963
pp. 187–188

FISHERIES HYDROGRAPHY. *By Ilmo Hela and Taivo Laevastu. Fishing News (Books) Ltd., London. 1962. 137 pp., 69 figs., 8 tables. £ 2 15s. 0d. ($7.70).*

The authors of *Fisheries Hydrography* boldly summarize in 98 pages of text (interspersed with 67 figures and 8 tables) better than half a century of investigation by marine scientists the world over. Reference is made to almost 280 technical papers and texts from which has been drawn material to support discussions on: (1) the environment's influence on fish behavior; (2) the application of hydrography to the more efficient pursuit of fish stocks; (3) the usefulness to the fisherman of meteorological reporting services; and (4) weather and hydrography in the prosecution of coastal (as contrasted to high-seas) fisheries. One may surmise from this that any attempt to cover so much ground in so little space could only have resulted in the most cursory treatment of the majority of researches cited. Such has unfortunately been the case, with the end product constituting not so much a real and useful synthesis of available data as an annotated but incomplete bibliography.

In all fairness, however, the authors make no pretense of their book's comprehensiveness. They state at the outset (p. 7): ". . . it is obvious that this presented text cannot be an extensive treatise of all the aspects of fisheries hydrography. Moreover, the approach has been directed by the specific individual interests of the authors, as is usual in most books. The authors have been courageous enough to make this approach in spite of the obvious limitations in its scope. . . ."

If the text be viewed from this perspective alone, then its usefulness as a reference for the beginning student of applied fishery science and oceanography, for the more astute fisherman, and, perhaps, for the layman, becomes immediately apparent. Accordingly, the authors are to be commended for a monumental effort. But, in their explanation of the book's purpose (p. 7), they curiously contradict themselves. They first state that "This book summarizes in a semi-popular manner and as simply as possible the principal results of research in the field of fisheries hydrography during the last six decades. It also shows how to apply facts and principals of oceanography and maritime meteorology to fisheries problems. . . ." Refuting the preceding one, the very next sentence says: "Obviously this book is not a 'how to do' manual but rather a textbook on the subject. It is primarily meant for fisheries biologists. . ."

The uncertainty with which rationales of cause-effect relationships in the marine ecosystem are universally imbued is first hinted at in Chapter 1 (p. 15) where the authors indicate that to define "fisheries hydrography" would not be feasible. Instead, they ". . . will try to describe [it] briefly, . . . and to show its relations to the neighbouring sciences from which it has been derived. . . ." The philosophy sustaining this approach, they relate, stems from an aphorism attributable to the French mathematician Poincare, namely (their words), ". . . that what we gain in exactness we usually lose in objectivity. Only by withdrawing from reality do we acquire perfect purity. . . ." Is this an apology for the fact that the research cited later has generally failed in the unbiased revelation of truly functional cause-effect relationships? Or does it represent a subtle justification for the inclusion of material about which the authors have hidden doubts? In any event, the reader is at least informed (perhaps inadvertently so) that "fisheries hydrography" is a science (?), but a really meaningful answer to the question heading Chapter 1, "What is fisheries hydrography?," is yet forthcoming.

One of the book's main difficulties seems to be its oversimplification, its allusion to the idea that a particular feature of the marine environment—by itself—can control directly the magnitude and distribution of individual fishery resources. This is not necessarily so. The factor limiting development at one instant may not be so the next. Instead, the actual situation is more likely to be rather complex, with the interaction of many factors defying description—at least in terms of our present measurement capabilities. On page 26, for example, the authors trap themselves in the quicksand of uncertainty when they pursue discussion under the topic "Temperature optima for adults and the influence of temperature on the abundance, migrations and shoaling of fish." They opine (reviewer's italics): "Nearly all fish stocks have *specific optimum* temperatures. . . . A thorough knowledge of these optimum temperatures is necessary for the prediction of fish concentrations. With such knowledge, predictions of temperature . . . can be used for predicting the seasonal abundance of a given stock of fish. . . ." But, only to undermine this somewhat assertive opinion, they go on to state: "The problem is further complicated by the fact that the *environmental requirements change* during the various stages of growth . . . , that the temperature requirements of certain species also change seasonally, at least in connection with spawning, [and] . . . [that] the concentration of food is temperature dependent, which makes the determination of the 'optimum temperature' for a fish *exceedingly complicated* in a few cases. In spite of this, the seasonal and year-to-year variations in thermal *and other conditions* will result in varying distribution and abundance on a given fishing ground. . . ."

Such careless exposition, which might be partly described as confounded speculation, can only leave the reader confused. What all of this indicates is an urgent need to reassess the methods by which our hypotheses of ecological cause-effect relationships have been and are being tested, to reject the majority which are now archaic, and to give greater consideration to some of the newer (albeit more sophisticated) ones, particularly the techniques of limiting-factor, multiple-factor, and time-series analysis.

The foregoing criticisms constitute but a few exceptions to a work that otherwise imparts a wealth of information, all of which, regardless of acceptability, reflects scientific progress in our never-ending search for knowledge of what transpires *in and above* the sea. And well the oceanographer might heed the timely advice the authors give regarding conditions at the *edge* of the sea (p. 104): "In this connection it must be pointed out that the oceanographers are neglecting the shallow seas and the coastal zones of seas even more than the marine biologists. Many of the shallow water problems are hydrodynamically perhaps less interesting—and because of their irregular appearance more difficult to approach—than those of the high seas. Nevertheless, the great and most many-sided significance of all the shallow seas to the marine biology, and to the fisheries as well means a challenge to all marine scientists. . . ."

One error in the glossary (p. 124) concerns the definition of *tychoplankton*, which the authors label ". . . organisms which spend part of their life-cycle as plankton, like the oyster larvae. . ." Actually tychoplankton according to Ruttner (*Fundamentals of Limnology*, Univ. of Toronto Press, 1953) are forms of the littoral community occurring in the plankton "accidentally," or adventitiously, such as sessile diatoms which break free under turbulen water conditions. Those organisms occurring as plankton during early life history stages are, before they assume a free or attached benthic existence properly classed as *meroplankton*.

Fisheries Hydrography, in general, does not read as smoothly as one might wish. Besides occasionally awkward and vague phraseology, some of which has already been discussed, grammatical inaccuracies are conspicuous by their frequency. Much of the responsibility for this lies with the book's editors, bu part of the difficulty could conceivably be attributable to the vagaries of translation (though there is no indication that the book was originally written in another language).

The selection of figures in support of the text is generally good, but their reproduction in several instances is far from satisfactory (*e.g.*, Figures 48–50 on pp. 79 and 80). Despite the book's unquestioned worth as a stimulus for better evaluation of biophysical and biochemical interactions occurring continuously beneath the surface of the sea, the above shortcomings do not seem to justify its relatively high cost.

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Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Fifteenth Annual Session, November, 1962
65-78

Expanded Research on Gulf of Mexico Shrimp Resources[1]

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Abstract

Given impetus through action taken in 1959 by the Gulf States Marine Fisheries Commission to reinforce a resolution it had passed 5 years earlier, the Federal program of research on shrimp supporting commercial fisheries in the Gulf of Mexico has since undergone considerable expansion. This is reflected in the size of its budget which in Fiscal Year 1959 stood at about $200 thousand but today, Fiscal Year 1963, amounts to nearly $750 thousand.

Carefully outlined are the current program's objectives as well as the general scheme of research being followed to attain them. Classed under the headings "Biology" and "Dynamics," individual projects are discussed in terms of the research techniques involved and the more significant findings that have resulted.

ERY QUIETLY beginning just before the outbreak of World War I and in esponse to early concern over the future of developing interests in a marine esource, which today supports the nation's most valuable commercial fishery, iological research on Gulf of Mexico shrimp stocks has since been characterzed by alternate periods of vigor and lapse.

Throughout its history, however, we do see a thread of continuity maintained y responsible State governments, particularly as evidenced from the documentd efforts of pioneer biologists such as Viosca, Gowanloch, Burkenroad, and iunter, among others. Unfortunately, limited funds consistently prevented heir undertaking the large-scale research programs necessary to solve the umerous and complex problems that arise with the harvest of any renewable esource. But lack of money certainly didn't deter them from playing major oles in the erection of a firm base from which future generations of biologists night launch such programs.

It wasn't until the early 1930's that the Federal Government, with its somewhat greater financial strength, entered the shrimp research picture. This venture, rovoked by the shrimp industry's solicitude for the resource itself, marked the tart of a period of considerably heightened research activity. Supplementing, et sharply contrasting with modest investigations already underway by local onservation agencies, the program conducted by the United States Bureau of Fisheries sought to reveal the intricacies of shrimp biology on a scale heretofore too broad and expensive to be undertaken. The program's results are well known and may be readily identified with a host of workers from among which the names of Weymouth, Lindner, Anderson, Pearson, and King may be ranked with those mentioned above as the pioneers of Gulf coast shrimp research.

Regrettably, this increased interest in shrimp biology and in the manifestations of resource exploitation failed to develop beyond the plateau reached the mid-1930's. With the advent of World War II it waned perceptibly a finally ceased altogether.

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[1] Contribution No. 170 of the Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

It must be remembered, however, that up to this point in the history of G shrimp research, the commercial fishery itself had not yet realized peak prod tion or efficiency, and had by no means exhausted its potential for expansi into new areas and the utilization of new species. Recall further that the ea (1880-1948) fishery and attendant biological research centered on the white common shrimp, *Penaeus setiferus,* with populations in the Delta (Louisia Mississippi) area yielding practically the entire domestic production. Statist show that annual production of white shrimp did not reach a maximum un 1945, but later history has also recorded, as many know all too well, that t likewise signaled the start of a gradual to sharply downward production tre that has not yet seen a reversal.

Concern over failure of the northern Gulf's white shrimp fishery and, as outgrowth, a keen desire for the development of any measures that might off a similar fate in new fisheries (particularly those for brown shrimp, *P. aztec* off Texas and northern Mexico, and pink shrimp, *P. duorarum,* off southweste Florida and in the Bay of Campeche), rekindled interest in shrimp resea generally. This renewed interest culminated in 1953 when the Gulf Sta Marine Fisheries Commission, an interstate compact ratified into law four ye earlier, invited marine scientists to outline a course of action best calculated improve the status of the shrimp resource, and hence solve many of t problems then facing the shrimp industry. A resolution passed the followi year requested the Federal Government to underwrite, develop, and particip in an expanded shrimp research program which featured in large degree t collective ideas presented by experts the year before.

The 1954 resolution did meet with some success in the form of a mod increase in research funds but, unfortunately, not in the degree of participati that might have been expected. Research activity by the Bureau of Commerc Fisheries, designated as the Commission's principal research arm, lagged the next four years, and it wasn't until 1959 that this agency drew up a resear program that merited Commission sanction. We can't escape the fact eit that during this period the Gulf coast shrimp industry experienced several its worst production years.

Amid the flurry of industry activity in 1959-1960, which saw an excell recovery in production from the two previous years (record-high production brown shrimp in 1960), the Commission quietly pursued the task of expedit procurement of implementing funds (roughly $500 thousand), the task to wh it committed itself upon endorsing the Bureau's new biological research progra Initial attempts were only partly successful, however, with an additional $1 thousand in Fiscal Year 1962 bringing the total shrimp research appropriat for that year to $450 thousand—the highest level yet attained but still w below that agreed upon as being necessary. Bolstered by outcries arising fr sharply reduced shrimp production in 1961, subsequent attempts proved co pletely successful, the $325 thousand appropriated in Fiscal Year 1963 (on of the $175 thousand level established the previous year) just meeting amount called for by the new program. With bold old and new programs n being fully subscribed, the amount budgeted for shrimp research by the Bur of Commercial Fisheries in Fiscal Year 1963 approached three-quarters o million dollars, nearly a fourfold increase over that budgeted in 1958.

The Bureau's present shrimp research program, containing most if not of the study items proposed at the Commission's 1953 meeting of experts, rep nts a series of working revisions dictated by successive changes in funding vels. The practical need for this is readily appreciated as is the fact that with ch revision, new problems and theories may be posed for consideration. Their ceptance tends to strengthen and at the same time clarify the approaches as ll as objectives documented in the original or basic program. To a degree is also reflects research progress.

Acting on behalf of the Gulf States Marine Fisheries Commission in such atters is its Shrimp Research Committee, a standing group of Federal and ate biologists established in 1961 to coordinate the technical activities of vernment agencies engaged in shrimp research. With the acquisition of a bstantial increase in its 1962-63 appropriation for shrimp research, the Bureau lled upon this Committee to adjudge the latest revision of its working program, cessitated by the new level of funding. Meeting in New Orleans in September 962, the Committee passed favorably on this "expanded" program, the details which are outlined below.

PROGRAM OBJECTIVES

Objectives of the Bureau's enlarged program of biological research on Gulf f Mexico shrimp resources are essentially the same as those designated today r investigations of fishery resources the world over. Broadly speaking, they re: (1) to promote efficient utilization of commercially important shrimp ocks; (2) to define, as well as understand the mechanics of, those factors rincipally responsible for fluctuations in supply and yield; (3) to predict the agnitude of supply; and, accordingly, (4) to prescribe by means of flexible egulations the kind and amount of fishing that will result in maximum continuing yields consistent with optimum resource maintenance. Attainment of hese objectives relies in very large measure on proper application of currently ccepted theories of fishing as well as population ecology (dynamics), and, o the extent that such theories reliably portray the complex nature of events n the history of exploited species, results in regulatory measures conducive o high-level maintenance and utilization of fish and shellfish resources.

For convenience, our research objectives may be classified as either long ange or intermediate. To the long-range category we assign those which involve detailed knowledge of the marine (and estuarine) environments and, in a ense, an ability to predict not only how environmental changes will affect commercial shrimp stocks, but also the changes themselves. We do not, of course, ossess the latter capability and will only do so when reliable methods for the ong-range prediction of weather and other factors are devised. In the meantime nd until the principal factors are determined, our search for causes of unexplained fluctuations in shrimp supply and yield must entail the long-term serial observation and systematic elimination of environmental variables and combinations thereof. Prediction of supply and subsequent regulation of fishing effort must therefore be set in terms of limits which reflect the environment's greater and lesser combined effects on stock survival (natural mortality), as observed over a relatively long period of time. The question naturally arising in the minds of these underwriting research programs is: What length of time is implied by the term *long range*? In the situation being discussed, it could amount to 10, 15, or even 20 years, depending on how well founded the research program is at its inception, how well we can assess all features of the environment, how much the environment varies, and how capable we are of handling the mass of data that will accumulate.

Objectives classed as intermediate are those which may or may not by themselves constitute the final solution to a specific question or problem, but whic generally play a major role in the attainment of long-range objectives such discussed above. They are many as well as varied and, like the long-range typ usually focus attention on some sort of relationship, the complete understan ing of which is prerequisite to sound fishery regulation. The following may cited as the more important ones set forth in the Bureau's new shrimp researc program: (1) to determine the relationships between size of spawning sto and number of resulting progeny; (2) to assess the serial effect of fishing size of (spawning) stock and hence yield; (3) to define the relationship betwe rates of growth and natural mortality so as to predict the average size (or ag of shrimp at the moment population weight reaches a maximum, and thereb acquire the information needed to promote efficient resource utilization; (4) ascertain for each of the important shrimp species the spatial relationship b tween offshore (marine) spawning areas and inshore (estuarine) nursery area an understanding of which would provide insight into the question of wheth or not parent stocks are discretely subdivided; and (5) as required by (1) an (2), to develop accurate methods for determining population size and (ag structure.

GENERAL SCHEME OF RESEARCH

As indicated above, stocks of three species sustain the Gulf coast shrim industry. Ranked according to the order in which they contribute to overa Gulf landings, they are the brown, pink, and white shrimp. With a modera amount of seasonal overlap, each of these exhibits in shelf waters a well-define distribution both bathymetrically and geographically. Accordingly, each speci represents at the center of its distribution the main objective of fishing interes located in the same general region, e.g., the brown shrimp in Texas, the whi shrimp in Louisiana, and the pink shrimp in Florida. Moreover, these shrim are characterized by a distinctive life history whose sequence of events mo or less dictates how large-scale investigations into their biology and dynami should be organized.

Briefly, protracted spawning takes place in the truly marine environment o shore. The demersal eggs hatch within a few hours after spawning with the r sulting larvae being planktonic for a short period thereafter, and hence subje to the prevailing pattern of ocean currents. In most cases, the larvae are tran ported, or move in some as yet unexplained manner, toward and through pass between barrier islands into broad and shallow estuaries. During transport th quickly undergo morphological transformation and, by the time they reach t bay entrances, are no longer planktonic larvae but rather postlarvae that ha taken on a bottom-living existence. Once in the bays, or so-called nursery area the young shrimp grow rapidly to juvenile and sub-adult size. Within a fe months they begin to migrate seaward to the spawning grounds where the li cycle, which takes between 1½ and 2 years, is completed. Depending on t locality, successive spawning groups or "broods" of shrimp may be subject to continual fishing from the time the juvenile stage is reached in the estuari to the time the broods pass out of existence on the offshore fishing (and spaw ing) grounds. In most Gulf areas, however, fishing effort is largely concentrat on the sub-adult and adult shrimp inhabiting oceanic waters from the surf about 50 fathoms.

The general scheme of research adopted in 1959 and later enlarged upon 1961 and 1962 by biologists headquartered at the Bureau's Galveston install tion, takes advantage of the shrimp's somewhat unique life history outlin above. Four distinct areas for study may be readily defined, each representi

hase in the continuing process of shrimp population development, and there-
re being separable on the basis of space and time criteria. These study areas
: (1) spawning populations (as treated separately from each species' "fish-
le" population, which may consist of immature as well as mature shrimp);
) eggs and larvae — oceanic; (3) postlarvae and juveniles — estuarine; and
) commercial (or fishable) populations. Such a breakdown greatly facilitates
ogram organization as well as operation, and helps to maintain program in-
grity in situations where expansion or curtailment become necessary.

Each study area may, in turn, be subdivided further according to whether
e work being undertaken is largely qualitative or descriptive in nature, or
hether it can be classed as principally quantitative. This is not meant to imply
at the two kinds of work are not closely complementary, but rather that they
ffer widely in the type of professional talents required. For convenience, the
rms "Biology" and "Dynamics," respectively, will be used to differentiate them.

BIOLOGY (LIFE HISTORY) STUDIES

pawning Populations

The emphasis here is on defining and describing concentrations of spawning
rimp, with such work on the three major species as well as on several of minor
d potential importance now underway. Specifically sought is information re-
rding the areal distribution of spawning units, and the intensity and chronology
f spawning activity itself. This information will aid in future attempts to deter-
ine the size of spawning units; in predicting egg production; in more accurately
lentifying the broods (or age classes) associated with periods of heightened
pawning activity; and in determining age at maturity in both male and female
opulation segments.

Two approaches are being employed to secure this information. In the case
f pink shrimp studies, conducted off southwest Florida under contract with
e University of Miami since 1959, the results of systematic sampling for eggs
nd early larvae (Fig. 1) provide a basis for drawing inferences on the prob-
ble distribution of the parent shrimp and the extent of their spawning activity.
n the case of studies on brown, white, and other shrimp off the northwestern
ulf coast, a similar approach is supplemented by directly sampling commer-
ial-size specimens in a systematic manner and then histologically examining
eir gonads to determine the exact stage of development. The probable centers
nd periods of greatest spawning activity can be mapped from the resulting
ata with more accuracy than by the first method alone. Other information
ecured incidentally relates to the spawning frequency of individual shrimp: the
ex ratio in spawning populations; fecundity; the physical characteristics of
pawning grounds; and environmental conditions at the time of spawning.

The Florida pink shrimp studies continue much as they have since their in-
eption. A modest increase in 1962 funds together with a slight alteration in
ontract scheduling will permit examination of year-to-year variation in spawn-
ng sites and intensity.

A sizable increase in funds for studying brown and white shrimp spawning
opulations in conjunction with the distribution and density of resulting larvae
s permitting greater sampling coverage in the northern Gulf, and thereby en-
ancing the kind and quantity of information being obtained. The enlarged
cope of this project is illustrated in Fig. 2 where we note that initial field
ctivity in 1961 involved biological sampling only within that area offshore to
0 fathoms and lying between Freeport, Texas, and Cameron, Louisiana. Fol-
owing expansion, the project now involves the same coverage bathymetrically

but embraces the much greater area extending roughly from Brownsville, Texa to Pensacola, Florida.

Distribution and Abundance of Eggs and Larvae

We share the widely held view that it is in the egg and larval stages of population development where answers to the vital question of what causes majo fluctuations in shrimp supply and yield are most likely to be found. Projec under this heading therefore constitute some of the more important of thos making up the overall research program. They are organized in such a way th different types of information serving different purposes may be gathere simultaneously.

Thus, measures of larval density obtained systematically along with variou kinds of oceanographic data provide a basis for (1) serially correlating abundance of larvae with environmental parameters to determine which govern t the greatest degree the amount of spawning activity and the survival of shrim broods during their early oceanic phase; (2) computing survival from larv to postlarval stages and determining the magnitude of variation in brood succes (3) determining the patterns through which larval shrimp are dispersed fro centers of spawning; and (4) deriving abundance indices with which to predi probable supplies of commercial-size shrimp four to six months later.

As indicated earlier, one such study being conducted under contract by th University of Miami since 1959 has yielded valuable preliminary informatio concerning the distribution of larvae (as well as the location and intensity spawning) for a population of pink shrimp off southwestern Florida (Fi 1). A similar but yet more intensive study on the eggs and larvae of brow white, and other less important shrimp comprising stocks fished in norther Gulf waters has also been underway since 1959.

The latter investigation developed from a rather small-scale though detaile survey which involved one chartered research vessel and was restricted to Low Galveston Bay and the nearby Gulf, to a much broader survey which now employs two vessels and covers the Gulf's continental shelf from the vicinity Brownsville, Texas, eastward to Pensacola, Florida, an expansion of considerab magnitude (Fig. 2). This project, as well as the one investigating spawni populations with which it is closely associated, depends entirely on biological ar oceanographic data obtained once every three to four weeks at each of 50 to stations distributed over the area just defined. Biological material in the for of commercial-size (mature) shrimp and contemporary fish fauna is sampl by means of conventional trawling gear. Shrimp eggs and larvae are taken carefully metered plankton samples using the high-speed, all metal, Gulf plankton sampler. Checks on variation in vertical and diurnal distribution both larval and adult forms are made as time and conditions permit. Physic and chemical features of the environment are measured during biologic sampling, with water temperature and water-mass dynamics now receiving t priority. Special recording instruments and bathythermographs aid in construc ing temperature profiles, and electronic (Savonius type) meters provide da on the direction and velocity of currents at all levels of the water column. T current-meter data are supplemented by those resulting from the retrieval drift bottles and bottom-drifters which are systematically released during ea sampling cruise.

Though having undergone only partial analysis, the biological data thus f obtained from the histological examination of gonads and the analysis of plan ton samples tend to corroborate an earlier finding based on the distribution weight-frequency modes in commercial shrimp landings, that the annual spaw

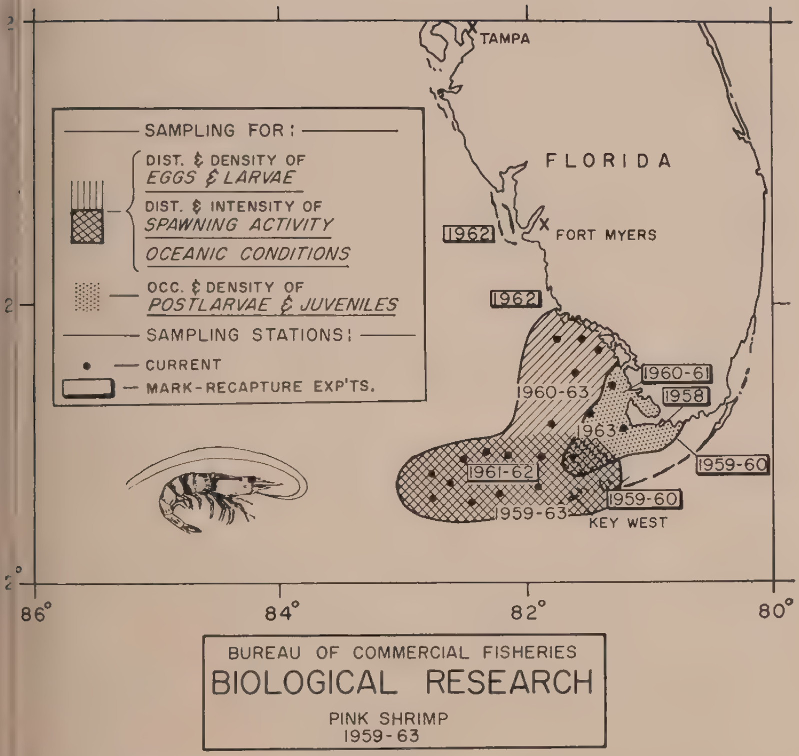
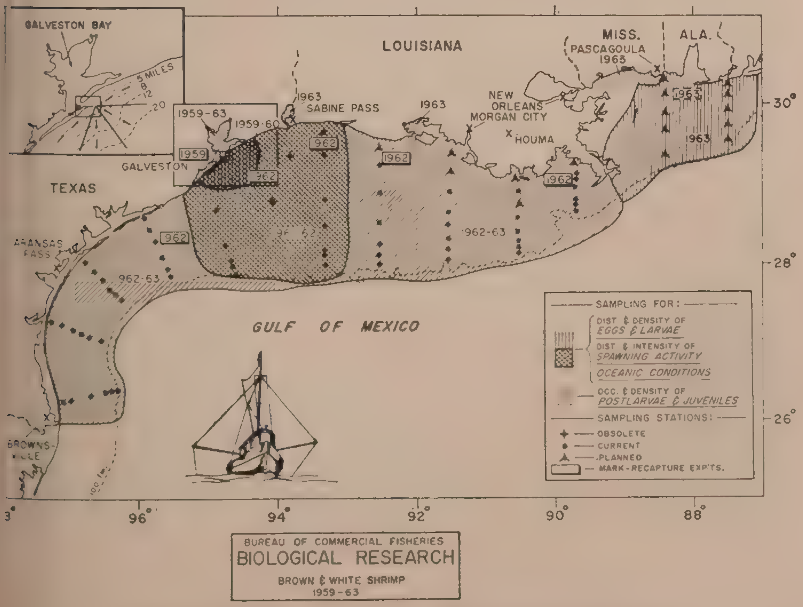

TAMPA
FLORIDA
FORT MYERS
KEY WEST
SAMPLING FOR:
DIST. & DENSITY OF EGGS & LARVAE
DIST. & INTENSITY OF SPAWNING ACTIVITY
OCEANIC CONDITIONS
OCC. & DENSITY OF POSTLARVAE & JUVENILES
SAMPLING STATIONS:
CURRENT
MARK-RECAPTURE EXP'TS.
1962
1962
1960-61
1958
1960-63
1963
1961-62
1959-60
1959-60
1959-63
86°
84°
82°
80°
BUREAU OF COMMERCIAL FISHERIES
BIOLOGICAL RESEARCH
PINK SHRIMP
1959-63

FIG. 1. Field operations off the Florida coast of the Gulf of Mexico.


GALVESTON BAY
5 MILES
8
12
20
LOUISIANA
MISS.
ALA.
PASCAGOULA
1963
1963
SABINE PASS
1963
NEW ORLEANS
MORGAN CITY
HOUMA
1959-63
1959-60
1959
GALVESTON
TEXAS
1962
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1963
1963
1962-63
1962-63
ARANSAS PASS
GULF OF MEXICO
BROWNSVILLE
100 fm.
30°
28°
26°
96°
94°
92°
90°
88°
SAMPLING FOR:
DIST. & DENSITY OF EGGS & LARVAE
DIST. & INTENSITY OF SPAWNING ACTIVITY
OCEANIC CONDITIONS
OCC. & DENSITY OF POSTLARVAE & JUVENILES
SAMPLING STATIONS:
OBSOLETE
CURRENT
PLANNED
MARK-RECAPTURE EXP'TS.
BUREAU OF COMMERCIAL FISHERIES
BIOLOGICAL RESEARCH
BROWN & WHITE SHRIMP
1959-63

FIG. 2. Field operations in the northern Gulf of Mexico.

ing cycle in the brown shrimp is characterized by two well-defined periods heightened activity. Preliminary analyses also suggest a strong correlation b tween relative density of larvae and prevailing (bottom) temperature. On t other hand, the possible role of water-mass movements in the distribution eggs and larvae cannot yet be reliably conjectured due to the short amount time this particular phase of study has been in progress.

Taxonomy of Immature Penaeidae

Beginning in 1959, this project arose out of a need by biologists working larval distribution and abundance for a means of separating the many speci of shrimp that occur together as similar-appearing larvae and early postlarv in the plankton. Best material to date has been secured by rearing and careful describing successive developmental stages of larvae hatched from eggs spawn in laboratory aquaria by parents of known identity. However, because of dif culty in carrying larvae beyond certain intermediate stages, only specimens the very early forms have been so obtained. Those morphological stages to whi rearing in the laboratory has not yet proved possible are described from plankt material surmised upon close scrutiny and comparison of external features represent the stages in question.

By means of these methods, tentative generic keys to immature Gulf Mexico Penaeidae have been constructed and are in use. The larval forms several species, namely the pink shrimp (under contract with the University Miami) and seabob, *Xiphopeneus kroyeri*, have been described in some deta The larvae of other species, particularly the brown shrimp, are receiving simil treatment, with the descriptions of several nearing completion. Present pla call for continuing this important project at about its present level of fundi until the immature stages of all overlapping species are satisfactorily describe The resulting information will be of inestimable value to all future workers shrimp research.

Movement and Density of Postlarvae

In the continuing process of population redevelopment, it is easily recogniz that there is and, in fact, quite logical that there be, a high serial correlati between the numbers of shrimp surviving from one life history stage to the ne The practical utility of this fact is, however, directly proportional to the c and general feasibility of identifying and sampling each stage in order to reliab assess it. If a situation exists where costs appear justified and the size of a shrin brood can be measured at a reasonably early stage in its development, we a provided with a device through which the availability of later supplies and su cess of the incident fishery may be predicted with a fairly good degree of c tainty.

Such a situation has always existed in the case of each of the three speci supporting our extensive Gulf of Mexico shrimp fisheries, but its real potent was not explored until initial efforts to do so were made in the Galveston ar at the start of the 1960 shrimp season. The life history event meriting clo attention is the concentrated movement of young shrimp toward and throu entrances to estuarine nursery grounds as they undergo transformation fr larval to early postlarval stages. Combined measures of their relative abundan obtained by frequently sampling these postlarvae in an efficient and consiste manner just inside a series of entrances or passes, exhibit considerable promi as valid indices to the later abundance of juveniles on the inshore nurse grounds, and commercial-size shrimp on the offshore fishing grounds. Shou such indices eventually prove their worth as predictive devices, the next consi eration will be their relative cost which, ultimately, would have to be bor ally by the State agencies responsible for resource management. Costs narily of sampling) could be expected to vary from area to area along the t depending on the topographical nature of the estuarine-marine transition , but every effort will be made to minimize these by giving sufficient prior ntion to the problem of expected variation in results, and the development e most efficient sampling gear.

good start in this direction is exemplified by the results of a three-year y (1960-1962) with brown shrimp in the Galveston area (Fig. 2). Re- ed elsewhere in these proceedings, they reveal very good correspondence een postlarval indices as obtained by sampling systematically inside Gal- on Entrance, subsequent indices of juvenile abundance throughout the veston Bay system, and still later indices of adult abundance off the upper as coast.

he success of this very modest investigation has prompted its expansion onsider index refinement as well as application in other coastal areas. Ac- lingly, additional funds appropriated for shrimp research in Fiscal Year 3 are being used not only to assess sources of index variation in the Gal- on area, but also to implement similar projects in western Louisiana, sissippi, and Florida. As of this writing, contracts have been awarded to Gulf Coast Research Laboratory to investigate the occurrence and density rown and white shrimp postlarvae in Mississippi Sound, and to the Uni- ity of Miami to investigate the relationship between the density of postlarval shrimp in Florida Bay estuaries and the later abundance of fishable adults the Tortugas fishing grounds (Figs. 1 and 2).

he prospects seem bright that the postlarval index will prove increasingly able as an aid to the shrimp industry in its annual task of preparing for forthcoming shrimp season. And although our current efforts are directed ard the development of postlarval indices that would predict conditions hin rather large coastal areas as a whole, it is quite likely that individual ices would adequately serve corresponding interests on a local scale.

boratory Studies — Physiology and Behavior

ounding out the program of research listed under the heading "Biology" several projects concerned with evaluating the effects of, and hence de- mining the relative tolerances of shrimp to, varying levels in each of a iety of simulated environmental factors. Growth, survival, metabolic rate, general performance are the experimental criteria employed, with post- val or juvenile shrimp in most cases making up the experimental populations. tors being tested include temperature, salinity, light, diet, dissolved gases, velocity of water currents. Circulating sea-water systems and specially structed rooms in which temperature and light can be precisely controlled ilitate experimentation.

ost recent findings suggest that juvenile (brown) shrimp can tolerate vider range of temperatures than can postlarvae. They indicate further that tlarvae and juveniles adapt equally well over a wide range of salinity levels that the range of tolerance to salinity narrows considerably as the tem- rature decreases. Such information as well as the results of other research be of great value in predicting the effects of environmental changes, es- cially those resulting from extensive engineering projects proposed for Gulf st marshes. Much of this information and, even more important, the research hniques now being developed to obtain it, will also prove useful in the ent plans materialize to undertake basic research in shrimp culture, a topic eiving more and more attention.

DYNAMICS STUDIES

Classed under this heading are those projects which, because of their ve nature, rely to a much greater degree on the use of mathematical and statistic techniques than do those listed above under “Biology Studies.” Mainly involv are the estimation of population parameters (especially those of growth a mortality) and their substitution in applied theories of resource dynami Statistics of catches and fishing (sampling) operations, whether they ar from the activities of research vessels or commercial fishing fleets, play major role in these processes as do the results of systematically executed ma recapture experiments.

Juveniles — Inshore Fisheries

Reliable measures of postlarval density also constitute, in addition to th potential as predictive aids for the shrimp idustry, basic elements in the calc lation of brood survival from the egg to postlarval stage, and, again, fro the postlarval to late juvenile or seaward-migrant stage. Statistics of insho (particularly bait-shrimp) fisheries that operate in most areas provide t means for obtaining rough measures of juvenile density against which cor sponding measures of postlarval density may be compared.

Although the adverse effect that inshore harvest of small sub-adult shri may have on the immediate supply of commercial sizes offshore is of so interest, of far greater concern in terms of future shrimp supplies are the lo range effects of man-induced environmental changes in the estuaries, partic larly those due to pollution and other causes of reduced water quality. attempts to ascribe and measure these effects, it would seem quite logi wherever brood identity can be maintained, that the ratio of postlarval dens to the subsequent density of seaward migrants serve as the primary varia to which should be related appropriate measures of those environmental ch acteristics believed to exercise greatest control over brood survival duri inshore phases.

Assisting such attempts are established or planned surveys that gather t statistical data without which meaningful results could not be obtained. F example, a continuing sample survey of the Galveston Bay bait-shrimp fishe begun in 1959 as a cooperative venture with the Bureau’s Branch of Statisti has more than paid for itself in terms of the valuable information on juven density that it has since yielded. Not only has this information served to su stantiate the validity of the postlarval index discussed in an earlier secti but it also stands to aid in completing studies of the kind just mentioned those involving assessment of changes in the estuarine environment. Plans give similar coverage to comparable fisheries in other areas are now be developed. In regions where such fisheries do not exist, projects which wo undertake the sampling of juveniles to obtain the desired information will so be implemented. Thus, the seasonal density of juvenile pink shrimp in Flor Bay, as related to both the corresponding densities of late postlarvae in Everglades and commercial-size adults on the Tortugas grounds, will be exa ined by different techniques and in different localities by a new Bureau proj as well as by a study proposed in connection with the new research contr awarded to the University of Miami.

Parent Stocks — Commercial Offshore Fisheries

Studies grouped under the general project heading “Population Dynami ” are or will be mainly concerned with refining and then employing shri catch and effort statistics to derive reliable indices of relative abundance

able stocks, which represent in part the spawning populations discussed
ier. Analysis of abundance trends and definition of factors governing them
also continue to receive attention, as will the problem of age assessment
, accordingly, the usefulness of commercial statistics in estimating mor-
y. Also of interest here are data suitable for the comparative study of
ing powers of different vessel and gear arrangements. All this information
o be used to evaluate the effect of fishing on the magnitude of shrimp
plies.

npling Commercial Catches

ommercial production and effort statistics are now made available monthly
the Bureau's Branch of Statistics. These are obtained by means of a con-
ing and rather intensive canvas (established in 1956) of all industry in-
lations located on the United States Gulf coast. Statistics of shrimp landings,
ained by inspection of dealer records, are broken down according to area
depth of capture, and species and size composition. Effort statistics, ob-
ed by interview, are recorded on the basis of number of fishing trips, time
nt fishing, and fishing position.

lthough the collection system and resulting statistics represent an admirable
rt, and the statistics themselves constitute extremely valuable information
n in their present state, there have arisen recognizable defects that it was
eed could be largely remedied with but a moderate amount of the right
d of effort. Improper identification of species, questionable validity of size
nposition data, and unreliable effort estimates have been designated as the
jor weaknesses. To check these and, in general, to aid in improving the
tistics overall, assignment of strategically located catch (port) samplers
s proposed. These persons would work closely with the statistical agents
ated in their respective areas and be responsible for sampling landings for
cies and size composition, and interviewing additional trawler captains for
ormation on fishing position and effort. Other duties would include: check-
on the extent to which small shrimp are discarded at sea during seasons
en this is widely practiced; aiding in the handling of marked shrimp re-
tured during growth and mortality experiments; and providing miscellaneous
logical data that might be required in the execution of other research pro-
ts.

Although the proposal to establish a pool of catch samplers was introduced
the Gulf States Marine Fisheries Commission as early as 1954, lack of
ds precluded action until seven years later (1961) when a supplemental
dget permitted assignment of samplers at Port Aransas and Galveston
exas), and Morgan City (Louisiana). With the additional funds allocated
Fiscal Year 1963, similar positions are now established at Brownsville
exas), Houma (Louisiana), Pascagoula (Mississippi), and Tampa, Fort
ers-Everglades, and Key West-Marathon (Florida), thus completing the
ol (Figs. 1 and 2).

ark-Recapture Experiments

Development of the stain-injection technique for marking shrimp, now
nowledged as being far superior to the method of tag attachment, has
atly broadened the scope of research on shrimp dynamics and expedited
measurement of key population parameters, namely, growth and mortality.
ccessful feasibility studies involving determination of dispersal patterns for
-adult pink shrimp migrating from various points in Florida Bay (1958-61),
d small brown shrimp migrating from Galveston Bay, Texas (1959), led

in 1961 to the technique's first large-scale application to measure growth a
mortality in fishable portions of commercial populations. Receiving init
attention was the well-known Tortugas (pink shrimp) population off sout
western Florida. Carefully planned and executed, this study yielded ve
good growth data, preliminary though useful measures of fishing and natur
mortality, and some indication that, because growth evidently cannot compe
sate for losses due to high natural mortality, regulations involving an increa
in minimum shrimp size would not lead to greater production.

With the increased research funds provided in Fiscal Years 1962 and 196
similar experiments involving other species elsewhere in the Gulf have alrea
been completed, are underway, or are being planned. During 1962, mark-r
capture experiments with brown and white shrimp off Louisiana and Tex
and pink shrimp in the Sanibel (Florida) area, will have terminated a
analysis of their results begun. In addition to these, attempts will also be ma
to define for the same species the spatial as well as seasonal (and annua
variation in estimates of growth and mortality parameters. Planned earli
as a repeat of the 1961 experiment mentioned above, the first such eff
was scheduled for the Tortugas pink shrimp population in late 1962.

In all mark-recapture experiments executed to date, vessel facilities provid
on a charter basis by the Bureau's Exploratory Fishing Base in Pascagou
Mississippi, have been used for shrimp capture and marking operations. Al
in this connection, the generous assistance of industry and Branch of Statisti
personnel in the recapture and recovery phases of each experiment mer
acknowledgement.

At its present rate of progress, dynamics research incorporating the mar
capture experiment as its primary tool should, together with concurrent a
alyses of fishery statistics, soon produce results which will permit prelimina
application of the population theory referred to earlier. This, in turn, will ma
possible at an earlier date than hitherto anticipated, rational decisions regardi
the kind and amount of fishing best calculated to serve the interests of maximu
continuing yields of shrimp consistent with optimum resource maintenance.

SUMMARY

Following a brief resumé of the early history of biological research on co
mercial shrimp resources in the Gulf of Mexico, attention is focused on eve
occurring over the period 1959-62. Given impetus through action taken
1959 by the Gulf States Marine Fisheries Commission to reinforce a resoluti
it had passed 5 years earlier, Federal participation in this activity has sin
undergone considerable expansion. This is reflected in the size of the Bure
of Commercial Fisheries shrimp research budget which in Fiscal Year 19
stood at about $200 thousand but today, Fiscal Year 1963, amounts to nea
$750 thousand.

Carefully outlined are the current program's long-range and intermedi
objectives, as well as the general scheme of research being followed to att
them. Program continuity and the quantitative approach are stressed throu
out, as is the fact that in several instances, independent means are employ
to achieve the same objective and thereby serve to cross-check the validity
intermediate or final results.

Classed under the headings "Biology" and "Dynamics" individual proje
are discussed in terms of the research techniques involved and the more s
nificant findings that have thus far resulted.

Individual fish from the inshore and high seas samples were classified into either of the two continental groups. Sample locations and results of classification are found in Table 15. All North American inshore samples were correctly classified into their continental group. Samples from the Alaska Peninsula and Northwestern Alaska were found to be distinguishable from the Asian standard. Individuals in the high seas samples were most frequently classified as Asian. However, three samples obtained on the North Pacific in the latter part of July were predominantly of North American type fish (Figure 30). One other sample obtained from the eastern Bering Sea on June 27 was classified as chiefly North American.

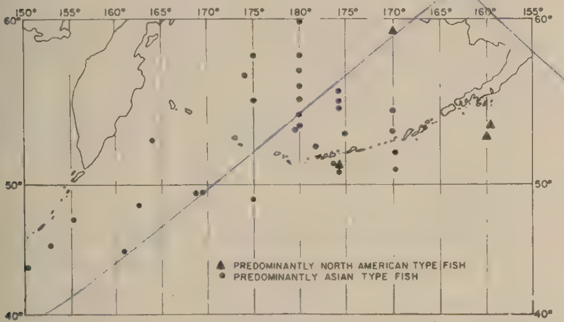

150°
155°
160°
165°
170°
175°
180°
175°
170°
165°
160°
155°
60°
50°
40°
▲ PREDOMINANTLY NORTH AMERICAN TYPE FISH
● PREDOMINANTLY ASIAN TYPE FISH

FIGURE 30. Classification of 1959 high seas samples of pink salmon into continental groups.

SUMMARY AND CONCLUSIONS

Morphological and scale differences between fish are being examined as a possible method of separating Asian from North American pink salmon in high seas samples. A preliminary study with the 1957 collections indicated additional characters were needed to distinguish fish of the Alaska Peninsula, Aleutian Islands and Northwestern Alaska from those of Asia. As a result, four new characters were added to the separation analysis after appropriate testing. The new characters were used with two from the previous study to classify the 1959 collections to continent of origin. In the 1959 collections, all North American inshore samples were distinguishable from Asian samples. However, only four high seas samples resembled North American type fish. The majority of samples were classified as Asian.

REFERENCE

AMOS, MURRAY H., RAYMOND E. ANAS AND ROGER E. PEARSON. 1960. Use of a discriminant function in the morphological separation of Asian and North American races of pink salmon, *Oncorhynchus gorbuscha* (Walbaum). U.S. Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Washington, October 12, 1960. 55 pp. Processed. (INPFC Doc. 412.)

CHUM SALMON STUDIES

by John LaLanne

The principal objective of this study has been to identify the continental origin of chum salmon taken at sea. A large number of chum salmon morphological characters (structures and body form) have been examined for possible consistent differences between Asian and North American chum salmon. The most useful characters have been the number of vertebral segments, the number of fin ray elements, and other segmented bony structures which have shown differences between populations of Asian and North American chum salmon.

We have applied these characters in a method which enables us to identify the continental origin of chums taken at sea with the exception of those from rivers entering the Bering Sea, and rivers of the Kodiak Island region. Because these rivers most likely contribute significant numbers of chums to the high seas area under study, we have begun examination of scale structures for possible differences between chums from these regions.

Chum salmon scales are flat calcified structures, generally round or oval in shape. Near the center is a platelet or focus. Circular or semicircular ridges (circuli) concentric to the focus occur on the anterior portion of the scale (Fig. 31). When scale growth is rapid, thick widely spaced circuli are formed; when growth is slow, narrow closely spaced circuli are formed. Since protracted slow growth usually occurs once annually in the winter, the band of narrow closely spaced circuli formed is called an annulus and is used in determining the age of the fish. Counts of the number of circuli and scale length measurements are the scale characters most commonly used to identify the origin of the fish.

International North Pacific Fisheries Commission, Annual Report 1961,
Vancouver, Canada, 1963, p. 119-124.

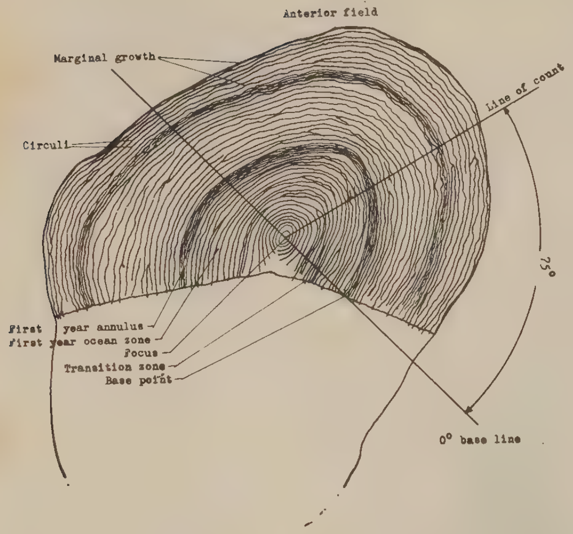


FIGURE 31. Diagram of chum salmon canted right scale with descriptive notations.

As a prerequisite to using scale characters for differentiating Asian and North American chums, it is necessary to evaluate the effect on the characters of such extraneous factors as differences in scale shape, the location on the fish's body from which scales are sampled, the area studied on the scale, the sex or age of the fish, and others. It is possible that supposed differences between chums from the two continents could be due only to these factors.

For example, if the number of circuli is different for scales sampled near the head of the fish and those sampled near the tail, then all scales must be taken from one or the other location. Otherwise, differences in number of circuli between Asian and North American chums would occur simply because North American chum scales were sampled, say, near the head and Asian scales near the tail.

Also, it is important to know the age of the fish so that the different age groups can be compared. The annual marks on scales have been used to determine the age of many species of fishes. Only limited study has been made of the scale method of age determination of chum salmon.

In 1961, chum salmon morphological research was directed toward evaluating the effect of extraneous factors on scale characteristics, developing methods of producing consistent and comparable scale data, and examining the validity of using scales for age determination.

EFFECT OF EXTRANEOUS FACTORS ON SCALE CHARACTERISTICS

Scale shape. It was found that with the exception of a few randomly distributed intermediate type scales, the scales on a chum salmon are of two general shapes, canted left and canted right (Fig. 31). The spacing and number of circuli change with scale shape. If a fixed line of count or measurement was established for all scales then a spurious difference between Asian and North American chums could result from more canted left scales being sampled from Asian chums than North American chums. Therefore scale shape must be considered when counting circuli or measuring scale lengths. The line of count or measurement should change with the scale shape.

Line of count and measurement. In an attempt to obtain consistent results, chum salmon scale counts and measurements have usually been made along or within certain limits on either side of the longest axis of the scale. The longest axis is generally established as the longest radius from the center of the focus to the periphery of the anterior portion of the scale or the edge of a particular annulus.

A comparison was made between the longest axis method of establishing the line of count and other methods. A base line on the scale from which a line of count can be projected was found to provide a more consistent line of count than the longest axis method (Table 16). The base line is defined as a line from the center of the focus to a base point where the first annulus enters the transition zone between the anterior and posterior portions of the scale (Fig. 31). There are two base points, one where the annulus enters the transition zone on the left and one on the right. The base point closest to the focus is used. The use of the closest base point accounts for scale shape. The closest base point is on the right for canted right scales and on the left for canted left scales.

TABLE 16. Comparison of angular variation within line of count by "base line" and "longest axis" methods. For each scale two determinations were made by each method.

Method	*N*	Min. diff. (degrees)	Max. diff. (degrees)	*S D*	Mean diff.
Base line	22	0.0	8.5	1.95	1.4
Longest axis	22	0.0	37.5	9.50	5.0

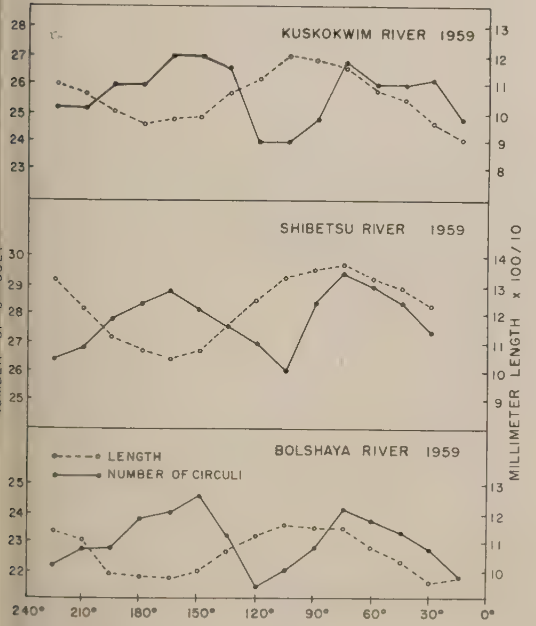
he closest base point is determined by measure- t. The base line is established on the right of the scale for the few scales having equally nt base points.

ffect of change in line of count. Having determined nsistent method of establishing the line of count, variation of scale characters with change in line ount was examined.

otal circuli counts and scale length measurements he first year zone (Fig. 31) were made at 15 degree rvals. The mean number of circuli and the n total length of the first year zone clearly differ change in the position of the line of count for scale shapes (Figs. 32 and 33). It is evident circuli counts and scale length measurements t be made along a particular line for consistency esults. A radial line at an angle of 75 degrees the base line for both canted right and canted scales was chosen for the following reasons:

For the areas and scale shapes sampled, these radial lines are at a position on the scale where the highest average number of circuli are formed over the greatest average length.

Irregular, broken and discontinuous circuli are not as frequent in the proximity of these radial lines as on other areas of the scale.



IGURE 32. Variation in mean number of circuli and mean length of first year zone of canted right chum salmon scales with change in position of angle of count. Five scales in each sample.

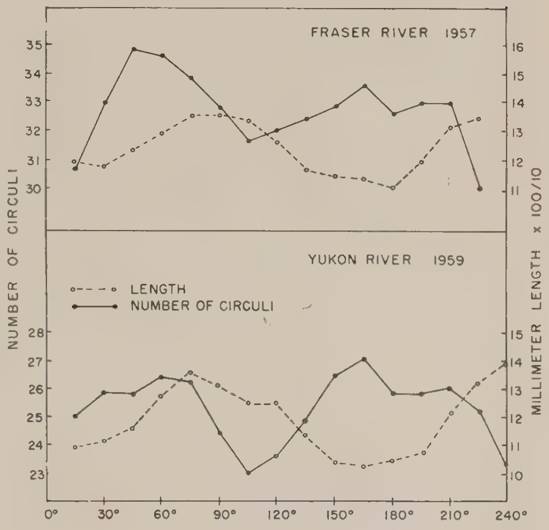


FIGURE 33. Variation in mean number of circuli and mean length of first year zone of canted left chum salmon scales with change in position of angle of count. Five scales in each sample.

Effect of scale regeneration. When a scale is lost from a chum salmon a new scale very quickly replaces the lost scale. The replaced or regenerated scale tends to have a scar-like appearance and few if any normal circuli. As the fish continues to grow, the scale resumes normal growth and it is generally assumed the replaced area maintains its scar-like appearance. Scales having regeneration scars in the area of study are discarded.

It was observed that the size and shape of the center or focus of chum salmon scales varies considerably and often is scar-like in appearance. This occurs not only on scales from different fish but also on scales closely approximated on the same fish. Possibly some scales having what has been considered a large " normal " appearing focus may actually be scales with regenerated centers. The very small scales on fingerling chum salmon 4–6 cm. in length generally have formed approximately from one to four circuli. It is possible that the scar left by scale replacement at the fingerling stage cannot in many cases be recognized on scales of older fish. This could be a serious source of error in studies using circuli counts because population differences could be obtained that were due only to the presence of undetected regenerated centers.

In lieu of further study, the circuli counts made in the first one-eighth of the length from the center of the focus to the outer edge of the first annulus will be recorded and analyzed in a manner so that their possible exclusion at a later date will not affect the analyses of other counts. The first one-eighth was arbitrarily chosen as that region at the center of the scale where the occurrence of regeneration would be most difficult to detect and because " large foci " were included in this region.

Variation of circuli counts with body position. Since all scales usually do not form on the body of fish at the same time, there is usually a difference in circuli counts with change in sampling location on the body.

Scales sampled from various body locations on a single chum salmon specimen caught in the Kuskokwim River on July 2, 1958, were examined in a preliminary attempt to determine the variation in first year circuli counts with change in body position of scales.

We were especially interested in the variation within the A and B sampling area (Fig. 28) on both the left and right side of the fish. The majority of chum salmon scales used in INPFC studies are sampled from these areas.

Body areas of four scales in a vertical row by ten scales in a horizontal row containing approximatel 40 scales were randomly sampled. Ten scales wei sampled from each body area included in the A an B body area and five were sampled from all others.

When collecting these data a reading techniqu which has been discontinued, resulted in larger tha normal reader error. Differences in mean first ye circuli counts of 0.5 circuli between any two bod areas could be due to reader error. The differenc in most cases exceed reader error and the data a satisfactory for the purpose intended.

There is considerable variation in mean first ye circuli counts with change in scale location on the bod (Fig. 34). There is an indication that scales from t A and B body areas both right and left side may considered similar in first year circuli counts. Scal outside these locations have been given the gener classification of C scales under INPFC scale sampli procedures (Fig. 28). Most of the C scales are low in mean first year circuli count than A and B bo area scales. Since a C scale is not recorded as bei sampled from a particular location within the C bo area, all C scales almost certainly will have to rejected as being significantly different from A a B body area scales if first year in ocean circuli cou are used as population indices.

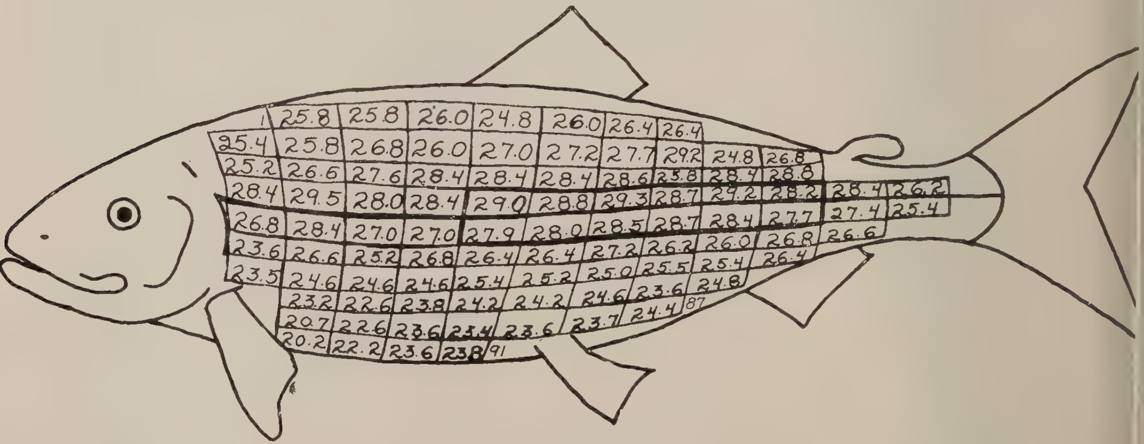


FIGURE 34. Mean number of circuli in first year zone of chum scales sampled from different body areas, left side. Heavy li encloses A and B area.

Additional study of the scale body area problem using different techniques and more specimens from several areas is planned.

Variation due to plastic impression method of duplicating scales. Plastic impressions of the original scale are generally used in most scale studies. There can variation in the quality of these impressions.

The possibility that circuli counts and scale leng are affected by variation in the quality of the pla impressions is being studied.

ge Determination from Chum Salmon Scales

mptions

he soundness of the method of using chum salmon s for age determinations depends on the validity he following basic assumptions:

Recognizable markings occur on the scale annually.

The annulus is formed during a particular period of time common to the species or the time of annulus formation is known for the individual specimens.

The position on the fish from which the scale is sampled has no effect on age determination.

Errors in age determinations made from scales showing signs of absorption (loss of scale material) at the scale margin are negligible.

nnulus and age of fish. The assumption that there recognizable age marks or annuli present on the es of chum salmon has been subjected to only ted critical examination.

bsolute proof of the validity of the assumption be obtained from scales of authentic marked of known age. For example, the scale of a m salmon marked as a young fry and recovered r spending three winters at sea should have three gnizable annuli present. In a preliminary mpt to test the assumption, 96 scales from known chum salmon were examined by two experienced m salmon scale readers. The scales were generously provided by the Washington State Department of heries and the Fisheries Research Board of Canada. scales were sampled from chums that were fin ked as wild fry and recovered as adults.

n most cases the known age of the chum salmon the age as determined from the scales was the e. Reader 1 rejected eight of the 96 scales ause of regeneration scars. Of the 88 scales read reader 1, only one was aged incorrectly. Reader ejected 15 scales because of regeneration and essive absorption. Reader 2 incorrectly aged ee of the 81 scales he deemed acceptable for age ermination.

cales from other areas and years may be more or difficult to interpret and other scales from marked m salmon should be examined. Nevertheless, s test gives strong support to the assumption that there are recognizable age marks (annuli) on chum salmon scales.

Time of annulus formation. It has generally been assumed that an annulus or band of narrow closely spaced circuli is formed on a chum scale in the winter due to a period of slow growth or complete cessation of growth. With the approach of spring it was assumed that new growth occurs and varying numbers of thick, widely-spaced circuli should be formed beyond the annulus by spring. The growth that occurs by spring should be somewhat less than the total growth that occurs for the entire growing season which is assumed to be from early spring to late fall. However, scale examiners have observed scales from chum salmon caught on the high seas in May that have a very large amount of growth at the edge of the scale. This presents a problem when attempting to determine the age of the fish from the scale. Is this large amount of growth "too much" to have occurred by May? If so, then it must be assumed that the growth at the edge of the scale is of the previous year and the annulus must not have formed as yet. If the examiner feels this is true he must add one year (one annulus) to the observed number. At present there is no scientifically established criteria for determining whether this growth is "too much" and errors of one year can occur when determining the age of high seas chums caught early in the year. Knowledge of the time or variation in time of annulus formation would aid in reducing this source of error. Attempts are being made to obtain scales sampled through the year and other data on scale growth are being assembled to obtain further information regarding this problem.

Scale body position and age determination. Generally an attempt is made to sample scales from a particular location on the body of the chum salmon for age determination. However, in many cases scales are missing or unreadable scales are found at the designated location and scales must be sampled from other body positions.

It is possible that all of the scales on a chum salmon are not formed early in life or there may be variation in scale growth such that all scales do not depict the same age. It is therefore important to test the validity of the assumption that all scales on a chum salmon depict the same age.

A random sample of 610 scales was taken from a single chum salmon specimen. The scales were randomly intermixed with other chum scales to eliminate bias when determining the age. All readable scales examined depicted the same age. However, on the basis of evidence from one fish only limited conclusions regarding this problem can be made. A more extensive study into this problem is planned using more specimens.

Absorption and age determinations. The majority of the scales sampled from chum salmon caught in streams and estuaries show evidence of absorption (loss of scale material) at the margin of the scale. When these scales are used to determine the age of the fish the reader must attempt to estimate the amount of absorption that has occurred. This estimate is generally based on the degree to which the margin of the scale differs in appearance from the normal. In other words, has the loss of scale material from the edge of the scale been great enough to remove one or more annuli? Generally no scientifically established method of measuring absorption is available.

It appears that errors of one or more years can be made when using partially absorbed scales for age determination. Further study of the effect of scale absorption on age determinations and of the possibility of using otoliths and other methods to supplement current procedures is in progress.

SUMMARY

Differences in meristic characters have enabled us to identify the continental origin of chums taken at sea with the exception of those originating from the Bering Sea coast and Kodiak Island region. Scale characteristics are being examined for possible differences which can be used to supplement meristic characters.

This report places particular emphasis on th methods and assumptions required in the use of chu salmon scale characteristics for population differe tiation and age determination studies.

A method of establishing a line of count an measurement that is consistent and also accounts f scale shape is described. Circuli counts and scal lengths differ with change in position of line of cou or measurement on the scale.

Regeneration of scales may be difficult to dete in some cases, especially in the central area of t scale. Variation of scale characteristics with chan in scale sampling area on the body is of sufficie magnitude to be a serious source of error in a stu designed to separate Asian and North Americ chum salmon. The quality of the plastic scale in pressions may affect the validity of scale racial dat Proof of the validity of age determinations ma from chum salmon scales is given by agreement scale age determinations with the known age marked fish. Lack of knowledge of the time annulus formation can result in errors of unknow magnitude in age determinations of chum salmo especially those taken early in the season.

Age readings of 610 scales sampled from a sing chum salmon specimen gave limited evidence su porting the assumption that all readable scales chum salmon have the same number of ann regardless of body position of the scale.

Age reading of partially absorbed scales are subj to errors of unknown magnitude. Studies design to solve these problems are in progress.

KING CRAB STUDIES

by Herbert Shippen and Takashi Miyahara

The year 1961 saw continuation of rapidly increasing fishing pressures on eastern Bering Sea king crabs. In 1960 one Russian and two Japanese motherships were operated; in 1961 two Russian and five Japanese motherships took part in the fishery.

By utilizing available catch statistics and announced production targets, we can estimate the catch of Japanese king crab operations in the eastern Bering Sea in 1961 to be about 3.5 million male crabs. For the two Russian mothership expeditions we can only guess that a combined total of about two milli crabs may have been taken. The estimated million crabs removed by these two nations is probab conservative and represents at least a fourfold incre in the catch of king crab in the eastern Bering S in comparison with the level of fishing during period from 1953 to 1958 (Fig. 35).

In addition to expansion of king crab fishing Japan and Russia, there have also been increa in groundfish operations. Although these fleets

Made in United States of America
Reprinted from Transactions of the American Fisheries Society
Vol. 92, No. 3, July, 1963
pp. 305–307

irth–Length Relationships in Sockeye and Chum Salmon

tches from several mesh sizes of gill nets e now used routinely to estimate selection es and to reconstruct the size composition sh populations. Among workers who have rted girth–length relationships in con- on with mesh selectivity are Margetts 57), McCombie and Fry (1961), Berst 1), Garrod (1961), and Gulland and ding (1961). A common procedure is to p fish by length classes, compute a mean h and length for each class, then give the ession of means as the girth–length rela- ship. By this procedure two workers could e different regression equations from the e data if they chose different length ses. Use of individual girths and lengths estimate the regression equation would inate this difficulty and guarantee consistency. Variability about regression may also be easier to interpret in the latter case. It should be noted that past work has not included confidence-interval estimates for mean (or modal) selection length or for the standard deviation of the selectivity curve.

The present paper gives girth–length relationships for sockeye and chum salmon (*Oncorhynchus nerka* and *O. keta*) ranging from 414 to 684 millimeters in fork length. Regressions are of individual girths on individual lengths.

METHODS AND MATERIALS

Salmon caught in four graduated mesh sizes of gill net during June 1961 in waters 30 to 325 miles south of the Alaska Peninsula and the Shumagin Islands provided data for this study. Lengths from tip of snout to fork of tail were read to the nearest millimeter from a measuring board. Girths were measured with a flexible steel tape just anterior to the insertion of the dorsal fin. This is approximately the point of maximum girth in sockeye and chum salmon of the stages of maturation considered here.

After measurement, fish were frozen for transport to the laboratory. After thawing, large or maturing gonads were weighed to the nearest gram; small or immature gonads to the nearest 0.1 gram. Sex was determined at the same time. For both species, gonad weights above 2 and 15 grams were taken to represent maturing males and females, respectively (Godfrey, 1961; Ishida, Takagi, and Arita, 1961).

LE 1.—*Girths, lengths, and girth–length regressions for sockeye and chum salmon taken in offshore ters of Alaska during June 1961*

[All measurements in millimeters]

cies, sex, maturity	Sample size	Girth			Length			Regression of girth on length	Variance about regression
		Mean	Range	Variance	Mean	Range	Variance		
ature ckeye									
Male	87	266	235–300	237	503	448–558	496	$G = -17.81 + 0.5630L$	81
Female	46	261	238–303	429	488	445–551	619	$G = -47.73 + 0.6315L$	186
hum									
Male	99	291	210–329	528	550	445–618	1 098	$G = -34.93 + 0.5931L$	140
Female	38	272	219–322	389	516	414–563	1,107	$G = 11.29 + 0.5070L$	107
uring ockeye									
Male	66	344	265–395	1,144	587	479–681	2,077	$G = -32.27 + 0.6409L$	311
Female	113	328	254–378	689	572	479–642	1,091	$G = -39.17 + 0.6426L$	240
hum									
Male	84	326	275–402	758	595	525–684	1,184	$G = -9.81 + 0.5651L$	385
Female	225	324	267–386	432	583	485–663	830	$G = 19.83 + 0.5210L$	314

TABLE 2.—*Girth–length regressions for groups of sockeye and chum salmon taken in offshore waters of Alaska during June 1961*

[All measurements in millimeters]

Group	Sample size	Regression of girth on length	Variance about regression
Immatures; species and sexes combined	270	$G = -12.33 + 0.5530L$	126
Maturing sockeye; sexes combined	179	$G = -44.14 + 0.6552L$	271
Maturing chum; sexes combined	309	$G = 14.85 + 0.5279L$	334

RESULTS

Table 1 gives statistics for each of eight basic groupings by species, sex, and maturity. In none of the groupings were departures from linearity evident in preliminary plots of the data. Therefore the hypothesis that a single line would describe girth–length relationships for both males and females was tested within each species and maturity group by analysis of covariance (Dixon and Massey, 1957). The conclusion in all four tests was that a single line would suffice for both sexes. This conclusion cannot be extended to inshore waters, where pronounced sexual dimorphism occurs near spawning time.

In both sockeye and chum salmon, girth–length relationships of immature and maturing fish were found to differ. For immatures, the conclusion of similarity between the sexes was extended to include species as well: a single regression line adequately described all immatures of Table 1. However, girth–length relationships were found to differ significantly between maturing sockeye and chum salmon.

In Table 2 are regression statistics for the groupings indicated by analyses of covariance: (1) all immatures, sexes and species combined; (2) maturing sockeye, sexes combined; and (3) maturing chum, sexes combined. Figure 1 shows the separate regression lines of Table 1 for the respective ranges of data. To facilitate comparison, the upper panel of Figure 1 includes a line for immature chums, sexes combined; the lower panel, a line for maturing sockeye, sexes combined. Positions of the lines in Figure 1 are consistent with the outcome of covariance analyses and with t combinations represented in Table 2.

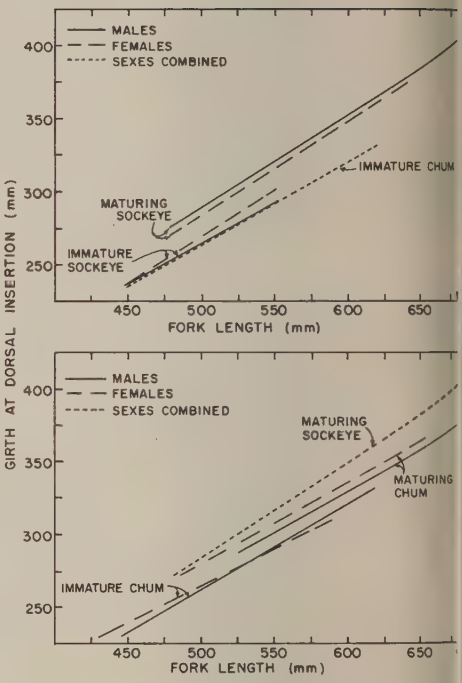


FIGURE 1.—Girth–length regressions of individu sockeye and chum salmon, grouped by sex a maturity.

ACKNOWLEDGMENTS

I wish to thank Messrs. G. Tanonaka and A. Haz wood for assistance in handling fish and for reco ing data. Gonad weights were determined by t Morphology Unit of the laboratory.

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tory. Of these fish 619 were taken by the U.S. red research vessel MV *Pioneer* in 1959 and ken by the same vessel in 1960; 1,510 were by the U. S. chartered research vessel MV *n* in 1960 and 138 were taken by Japanese in 1959. Of these, 1,608 were females and ve positive tests for the female maturity (Sm) n.

E 12. The correlation of gonad weight with presence Sm antigen in the sera of female chum salmon.

weight (gr.)	Total females tested	Number positive	Percent positive
<8	165	8	4.9
8–9	121	22	18.9
10–11	71	18	25.4
12–13	90	34	37.8
14–15	21	7	33.3
16–17	14	8	57.1
18–19	14	10	71.1
≥20	253	250	98.8

le 12 shows the correlation between gonad t and the possession of Sm antigen by female salmon. If the possession of the Sm antigen good indicator of maturation one can be quite n that a female chum salmon with gonads ing 20 or more grams is maturing. For those gonads weighing less than 20 grams there is derable uncertainty which possibly can be ved by tests for the Sm antigen.

order to have additional criteria for maturity lmon, we collected and fixed gonad samples rd the MV *Paragon* in 1960 for histological es. These studies were conducted by Dr. E. M. d and a manuscript describing the results is submitted. They may be summarized as vs: Maturing salmon gonads pass through a of structurally well defined stages. Active natogenesis and the onset of sexual maturation ars to begin when the first spermatogonia are ed. Active oogenesis apparently starts with the ation of secondary oocytes and the appearance e two layered zona radiata.

SUMMARY

1. Research on serology has been continued along three main lines in studies on red blood cell antigens, serum antigens and on maturity.

2. In the studies on red blood cell antigens a great many additional reagents have been studied. These include heterimmune sera produced in rabbits, chickens, goats and carp; normal sera of many domestic and wild mammals and fish; isoimmune sera produced in rainbow trout; and phytoagglutinins from plant extracts.

3. Clear cut qualitative intraspecific variations in the blood cell antigens of red, pink and chum salmon were demonstrated with five rainbow trout isoimmune sera. Significant differences among Bristol Bay populations of red salmon were demonstrated with two of these sera.

4. In studies of serum antigens 50 rabbits were immunized and serum from 250 bleedings collected and studied. Of these 122 gave evidence of individual differences in red salmon. Evidence was obtained which indicated that the presence of hemoglobin in lysed blood preparation influences the tests for some variable serum components.

5. The method of immunoelectrophoresis was adapted to the study of serum antigens of salmon.

6. Certain plant extracts were found to specifically precipitate with salmon sera. Some detect interspecific and intra-specific differences.

7. In order to assist in determining the maturity of salmon collected on the high seas, the heart bloods of 2,955 chum salmon have been tested for the presence of an antigen which occurs in the blood of maturing females.

8. A study of the histology of salmon gonads has been made to assist in establishing criteria for maturity.

MORPHOLOGICAL CLASSIFICATION OF 1960 RED SALMON

by B. J. Landrum and T. Dark

nce 1955, the morphological differences between principal races of red salmon were examined g multivariate analytical techniques. On the basis of the results from tagging, parasite studies and distance function analysis of morphological characters, it was concluded that the maturing red salmon in the

ternational North Pacific Fisheries Commission, Annual Report 1961,
ncouver, Canada, 1963, p. 108-114.

Table 11. The relative numbers of red salmon from six Bristol Bay streams reacting with two rainbow trout isoimmune sera.

Serum	Area	Number tested	Number reacting	Percent reacting
96	Kvichak	72	42	58.3
	Branch River	25	8	31.2
	Wood River	10	2	20.0
	Egegik	16	4	25.0
	Ugashik	12	3	25.0
	Naknek	12	5	41.7
		$X^2 = 12.82$*		
101	Kvichak	72	46	63.9
	Branch River	25	17	68.0
	Wood River	10	5	50.0
	Egegik	16	8	50.0
	Ugashik	12	12	100.0
	Naknek	12	11	91.7
		$X^2 = 13.07$*		

* Significant at the 95 percent level.

The application of these sera directly to the Protocol problem will undoubtedly require testing blood from freshly caught salmon in Asian areas and in areas of suspected intermingling of Asian and American stocks. (This is due to the fact that salmon blood cells are not preserved intact for any appreciable time by techniques presently available.) The relative availability of fresh blood from salmon caught by North American shore based fisheries allows us to apply these sera now to problems important to the understanding and management of these fisheries.

Research on Serum Antigens

The demonstration of characteristics designated antigens I and II which were present in 95 to 98 percent of red salmon blood samples tested from American areas and absent from 85 to 90 percent of red salmon blood samples tested from Asian areas has been reported previously. Further practical expansion of these results has met with difficulties of two sorts. The first involves the difficulty in producing sufficient antisera of the same specificity to test large numbers of samples. The second difficulty involves the resolution of apparent discrepancies between the results obtained with this method and those obtained with other methods of determining the continental origin of red salmon taken in the high seas.

In our report of last year we stated: "We feel it is essential to make a more thorough study of the nature of the difference being detected, and the effect of such variables as may be introduced by sampling and preservation methods, before furt application of this method is possible. It will be essential to perfect methods for the consistent p duction of large quantities of potent and spec antisera." In our attempts to solve the problem antiserum production we have immunized 50 rabl and collected and tested serum from 250 bleedi Of these sera 122 show definite individual differen We are conducting extensive tests by several meth to compare the specificities of these sera with th detecting previously studied differences. One the methods being used for these comparisons immunoelectrophoresis. A separate manuscr describing some of our results with immunoelect phoresis will be submitted. One most signific finding so far is that the interaction of the hemoglo in hemolysed blood under certain conditions interfere with the tests for important serum co ponents. This is especially true of three serum char ters discovered after antigens I and II. These h been designated H, H′ and C. We have been and studying this problem intensively by a variety methods. For two years now personnel of the serol investigations have accompanied charter vessels collect separated serum samples and study the feasi ity of conducting some of our tests on board th vessels. All of our work indicates that facili must be available on research vessels to oper centrifuges, separate the serum from fresh unhemoly blood, and conduct agglutination tests directly board before we will be able to accurately apply reagents we have available to the study of high s populations.

Certain plant extracts have been found to p cipitate soluble components of various fish sera i manner analogous to immune sera. Among th four have demonstrated individual variation various salmonid species. The specificities of th reagents when compared by double diffusion h been found to be independent of one another as as independent of the specificities of immune reage tested. Although extensive tests with these reage have not been made, further study on prop preserved samples may show that the serum com nents detected by these plant extracts are us racial markers.

Research on Maturation in Salmon

We have previously reported the discovery of antigenic fraction which apparently occurs in serum of only maturing or mature female salm In the past year we have tested the heart blood f 2,955 chum salmon being processed by the morphol s north and south of the Aleutian Islands were of western Alaskan or southwest Kamchatkan . Consequently, discriminant function analysis utilized to estimate the proportions of western an and southwest Kamchatkan morphotypes in seas samples collected in 1956 and 1957 (Fuku- *et al.*, 1959). Results of similar classificatory dure using the 1958 and 1959 samples were nted by Fukuhara (1960).

is report presents the results of classifying the seas samples taken in the North Pacific Ocean Bering Sea in 1960.

CLASSIFICATION OF 1960 SAMPLES

e red salmon runs into Bristol Bay were ex- ly large in 1960. The total was given as about *illion fish* by Royce (1961). It is reasonable to ne that prior to their arrival in the Bay, these fish dominated the maturing red salmon popula- in large areas of the North Pacific Ocean and g Sea. Particularly in the eastern Bering Sea of 180° longitude) it is reasonable to assume that ng the period of sampling, Bristol Bay stocks y dominated. This condition provides a unique mstance to evaluate the efficiency with which discriminant function classifies western Alaskan on taken on the high seas. Under these circum- es, if the discriminant function as applied is ent, the fish in all samples of matures taken in astern Bering Sea should classify almost entirely ristol Bay morphotype. Deviations from this ably can be best interpreted as a result of the om sampling variation which occurs in sampling ol Bay stocks at sea.

1960, inshore sampling was limited to six ipal streams in Bristol Bay. As in past years, les were obtained from the Wood, Kvichak, ek, Egegik and Ugashik Rivers. In addition, mple was obtained from the Branch River which s into Kvichak Bay. No samples were available the Kamchatkan mainland (as in 1959) or the Okhotsk Sea (as in years prior to 1959).

igh seas sampling was comparatively good in the ern Bering Sea but rather poor in the western ng Sea. Sampling in the Aleutian region of the th Pacific Ocean was fair north of 50°N. latitude. y few samples, however, were obtained south of latitude or in the southwest Aleutian region.

the absence of samples from the Kamchatka insula or the Okhotsk Sea, it was necessary to select samples from an alternative area southeast of the Kamchatka Peninsula and west of 165°E. longitude to represent the Kamchatkan population. Of the available samples only those containing greater than 100 specimens were selected. These samples were collected on June 3, June 18 and July 6 at 52°37′N. latitude, 164°18′E. longitude; 53°13′N. latitude, 164°44′E. longitude; and 49°22′N. latitude, 162°43′E. longitude, respectively. Using gonad weight criteria (Ishida and Miyaguchi, 1958), these samples were observed to be 98, 92 and 94 percent mature fish. Considering that these fish were on their spawning migration, it is a reasonable assumption that they were samples of Kamchatkan red salmon, for the area and time of capture make it very improbable that they were Bristol Bay salmon. All evidence from past research has indicated that the area in which these samples were taken contained predominantly mature Kamchatkan red salmon (International North Pacific Fisheries Commission, 1960).

Assuming that the maturing red salmon in the high seas areas sampled were either of Bristol Bay or Kamchatkan origin, the discriminant function, constructed on the basis of the 1956 collection (Fukuhara *et al.*, 1959), was applied to the 1960 collection. Using the average errors of misclassification of the 1960 Bristol Bay inshore samples and the Kamchatkan reference samples, the corrected percentages of the two types present in the high seas samples were calculated. The average error of misclassification of Bristol Bay salmon was weighted according to the relative abundance of red salmon in principal Bristol Bay streams as estimated from escapements.

TABLE 13. Average error of classification weighted according to the relative abundance of the contributing stocks of western Alaskan red salmon in 1960.

Area	Escapement in millions in 1960	Relative abundance	Observed percent of misclassification	Weighted value
Egegik River	1.798	.0824	29.1	2.3978
Ugashik River	2.304	.1056	20.7	2.1859
Kvichak River	14.630	.6706	16.6	11.1320
Wood River	1.016	.0466	28.2	1.3141
Naknek River	.828	.0380	38.3	1.4554
Branch River	1.240	.0568	57.6	3.2717
TOTAL	21.816	1.0000		21.7569

Average errors in classification:

For the western Alaskan population (Pa) = 21.7569%

For the Kamchatkan population

$$(\mathrm{Pb}) = \frac{22.5 + 21.8 + 34.9}{3} = 26.4000\%.$$

The average error of misclassification, weighted according to the relative abundance of the Bristol Bay red salmon population, was 21.8 percent (Table 13). This error of misclassification falls between a relatively small error (17.8 percent) in 1956–1957 and larger errors in 1958 (22.6 percent) and 1959 (23.6 percent). The Branch River which was not used in previous analyses contributed 5.68 percent of the Bristol Bay escapement. The single sample obtained from this river had a rather large percentage of misclassified specimens which increased the averag error of misclassification.

The average error of misclassification of th Kamchatkan samples was 26.40 percent. Previousl the Kamchatkan error of misclassification was abou 23.7 percent for the Okhotsk Sea samples in 1956–1957 29.1 percent in 1958, and 36.6 percent in 1959, fo a sample from the Ozernaya River.

TABLE 14. Results of discriminant function analysis, 1960 high seas red salmon samples.

Sample number	Sampling date	Position of sample		Sample size	Percent classified		Corrected percent western Alaskan type	90 percent confidence interval[1]	Percent mature
		Latitude	Longitude		Western Alaskan type	Kamchatkan type			
1	7/14	49°59′N.	160°50′E.	42	40.48	59.52	27.2	3–51	90
2	7/6	49°22′N.	162°43′E.	109	34.86	65.14	16.3	2–31	94
3	6/3	52°37′N.	164°18′E.	119	21.85	78.15	0	0–13	98
4	6/18	53°13′N.	164°44′E.	111	22.52	77.48	0	0–13	92
5	7/11	50°46′N.	166°48′E.	117	31.62	68.38	10.1	0–24	88
6	5/28	46°32′N.	167°47′E.	233	37.77	62.23	21.9	12–32	96
7	6/6	48°00′N.	168°00′E.	55	32.73	67.27	12.2	0–32	—
8	6/10	54°06′N.	169°43′E.	48	47.92	52.08	41.5	19–64	—
9	5/30	52°00′N.	170°00′E.	36	44.44	55.56	34.8	8–61	100
10	5/28	50°07′N.	170°04′E.	57	47.37	52.63	40.4	19–61	93
11	7/8	49°00′N.	170°06′E.	47	29.79	70.21	6.5	0–28	19
12	5/30	52°42′N.	171°37′E.	117	40.17	59.83	26.6	12–41	97
13	7/16	52°22′N.	172°50′E.	118	58.47	41.53	61.9	48–76	4
14	7/19	51°20′N.	173°00′E.	54	50.00	50.00	45.5	24–67	7
15	7/17	52°00′N.	173°00′E.	78	56.41	43.59	57.9	40–76	5
16	7/18	51°39′N.	173°02′E.	120	53.33	46.67	51.9	37–66	6
17	6/28	59°41′N.	173°42′E.	115	30.43	69.57	7.8	0–21	93
18	6/29	50°59′N.	174°55′E.	76	40.79	59.21	27.8	10–46	19
19	6/30	50°01′N.	175°03′E.	98	38.78	61.22	23.9	8–40	14
20	6/8	53°37′N.	175°54′E.	38	71.05	28.95	86.1	63–100	89
21	8/1	50°20′N.	178°00′E.	117	64.96	35.04	74.4	60–88	2
22	7/28	51°00′N.	178°00′E.	160	71.25	28.75	86.5	75–98	2
23	7/27	51°20′N.	178°00′E.	123	70.73	29.27	85.5	72–98	12
24	7/29	50°39′N.	178°02′E.	116	58.62	41.38	62.1	48–77	5
25	6/23	54°57′N.	179°23′E.	40	67.50	32.50	79.3	56–100	100
26	6/5	50°02′N.	179°59′E.	49	57.14	42.86	59.3	37–82	92
27	6/6	51°00′N.	179°59′E.	115	69.57	30.43	83.3	70–97	100
28	7/3	50°02′N.	178°36′W.	45	57.78	42.22	60.5	37–84	6
29	6/7	51°04′N.	178°30′W.	118	82.20	17.80	100.0	88–100	92
30	6/15	53°17′N.	178°17′W.	119	84.03	15.97	100.0	88–100	100
31	6/19	54°03′N.	177°05′W.	168	82.14	17.86	100.0	90–100	98
32	6/20	55°01′N.	176°58′W.	121	85.95	14.05	100.0	88–100	100
33	6/18	53°00′N.	176°58′W.	111	88.29	11.71	100.0	88–100	98
34	7/4	51°20′N.	176°45′W.	83	62.65	37.35	69.9	53–87	27
35	8/14	51°28′N.	176°30′W.	170	67.06	32.94	78.4	67–90	10
36	8/17	51°00′N.	176°30′W.	145	64.83	35.17	74.1	62–87	3
37	8/18	50°40′N.	176°30′W.	151	62.91	37.09	70.4	58–83	2
38	8/20	50°20′N.	176°30′W.	134	67.16	32.84	78.6	66–92	1
39	6/15	53°00′N.	176°10′W.	115	81.74	18.26	100.0	88–100	100
40	6/28	58°28′N.	176°07′W.	121	74.38	25.62	92.5	80–100	96

Continued . . .

TABLE 14. (continued)

S nple r nber	Sampling date	Position of sample		Sample size	Percent classified		Corrected percent western Alaskan type	90 percent confidence interval[1]	Percent mature
		Latitude	Longitude		Western Alaskan type	Kamchatkan type			
41	6/16	54°01′N.	175°38′W.	113	84.96	15.04	100.0	88–100	100
42	6/18	56°01′N.	175°00′W.	61	70.49	29.51	85.0	66–100	97
43	5/29	45°00′N.	175°00′W.	56	66.07	33.93	76.5	56–97	2
44	6/19	57°01′N.	174°59′W.	43	83.72	16.28	100.0	80–100	73
45	6/20	56°42′N.	173°27′W.	120	75.83	24.17	95.3	83–100	100
46	7/11	51°29′N.	173°04′W.	130	60.00	40.00	64.8	51–78	32
47	7/12	51°09′N.	173°01′W.	100	64.00	36.00	72.5	57–88	36
48	7/15	50°29′N.	173°00′W.	31	54.84	45.16	54.9	26–83	14
49	7/7	53°44′N.	173°00′W.	48	64.58	35.42	73.6	52–96	71
50	7/13	50°50′N.	172°59′W.	68	54.41	45.59	54.0	35–73	22
51	6/28	50°07′N.	171°43′W.	83	55.42	44.58	56.0	39–73	12
52	6/21	56°21′N.	171°41′W.	117	76.92	23.08	97.4	85–100	99
53	5/24	50°06′N.	171°40′W.	85	72.94	27.06	89.8	74–100	93
54	5/23	51°04′N.	170°49′W.	114	78.07	21.93	99.7	87–100	100
55	6/27	51°18′N.	170°37′W.	69	68.12	31.88	80.5	63–98	56
56	7/19	51°13′N.	170°02′W.	116	58.62	41.38	62.2	48–77	8
57	7/18	50°54′N.	170°02′W.	167	56.29	43.71	57.7	45–70	18
58	6/23	55°00′N.	170°01′W.	93	76.34	23.66	96.3	82–100	100
59	7/20	51°32′N.	170°01′W.	112	67.86	32.14	80.0	66–94	40
60	7/23	52°15′N.	170°00′W.	66	68.18	31.82	80.6	62–99	49
61	7/17	50°29′N.	170°00′W.	59	57.63	42.37	60.2	40–81	18
62	6/22	55°58′N.	169°59′W.	120	85.00	15.00	100.0	88–100	100
63	6/24	54°00′N.	169°59′W.	120	65.83	34.17	76.0	62–90	100
64	6/25	53°20′N.	169°59′W.	117	78.63	21.37	100.0	88–100	100
65	7/21	51°51′N.	169°59′W.	211	64.45	35.55	73.4	63–84	15
66	6/26	52°15′N.	169°57′W.	64	62.50	37.50	69.6	50–89	88
67	7/25	53°05′N.	166°05′W.	33	42.42	57.58	30.9	4–58	76

[1] Lower limit truncated at 0 and upper truncated at 100 percent.

igh seas sample locations and summarized results assificatory analysis are presented in Table 14.

ering Sea 1960

ay and June.—The point estimates of the pro- ion of the alternative red salmon stocks in all ples taken east of 175°54′E. longitude indicated verwhelming dominance of Bristol Bay morpho- (Fig. 24). With the exception of samples 25 63, all were estimated to contain greater than ercent Bristol Bay morphotype. Thirteen of the amples east of 178°17′W. longitude contained ter than 90 percent, with nine of the 13 con- ng 100 percent Bristol Bay morphotype. Samples nd 63 were estimated to be 79 and 76 percent ol Bay morphotype respectively.

ith the exception of sample 63, the upper 90 ent confidence limits for the point estimates ded 100 percent. The upper 90 percent con- nce limit for sample 63 was 90 percent. Due to its occurrence among samples for which point estimates were near 100 percent, the failure of the upper confidence limit of sample 63 to include 100 percent is interpreted to be attributable to random variation in sampling Bristol Bay stocks at sea. This does not preclude the possibility, however, of the actual presence of a small percentage of Kamchatkan red salmon or fish from areas other than Kamchatka and Bristol Bay.

West of 175°E. longitude only two samples were obtained. Eight percent of sample 17 which was taken on June 28 at 59°41′N. latitude, 172°42′E. longitude was classified as western Alaskan morphotype. Sample 8 was estimated to contain 42 percent Bristol Bay morphotype.

July and August.—Only one sample (49) was obtained from the Bering Sea in July (Fig. 25). This was taken on July 7 at 53°44′N. latitude, 173°W. longitude and was predominantly mature fish (71 percent).

Bristol Bay morphotype were estimated to compose 74 percent of this sample. No samples were obtained from the Bering Sea in August.

North Pacific Ocean 1960

May and June.—Eighteen samples (Fig. 24) were taken in the North Pacific Ocean during May and June, one containing 88 percent and 11 containing greater than 90 percent maturing salmon. Samples 18, 19, 43, 51 and 55 contained a comparatively high percentage of immatures. Data on maturity were not available for sample 7.

Bristol Bay morphotype dominated the nine samples taken east of 179°59′E. longitude. Six of these nine samples, mostly of mature salmon, were estimated to contain from 59 to 100 percent Bristol Bay morphotype, the lowest percentage occurring in sample 51.

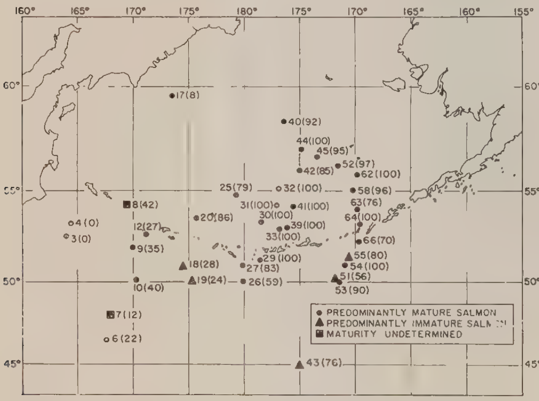
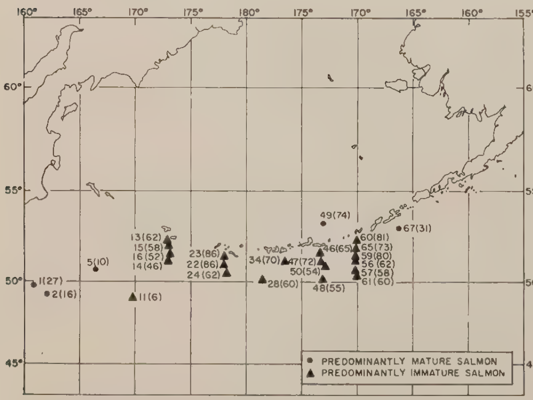

160°
165°
170°
175°
180°
175°
170°
165°
160°
155°
60°
55°
50°
45°
17(8)
40(92)
44(100)
45(95)
52(97)
42(85)
62(100)
25(79)
32(100)
58(96)
8(42)
31(100)
41(100)
63(76)
4(0)
3(0)
12(27)
20(86)
30(100)
39(100)
64(100)
33(100)
66(70)
9(35)
29(100)
55(80)
18(28)
27(83)
54(100)
10(40)
19(24)
26(59)
51(56)
53(90)
7(12)
6(22)
43(76)
● PREDOMINANTLY MATURE SALMON
▲ PREDOMINANTLY IMMATURE SALMON
■ MATURITY UNDETERMINED

FIGURE 24. Percentage of samples classified western Alaskan type—May and June, 1960. First number indicates sample number; second number percent western Alaskan type.


160°
165°
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175°
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175°
170°
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160°
155°
60°
55°
50°
45°
49(74)
67(31)
13(62)
15(58)
16(52)
14(46)
5(10)
23(86)
22(86)
24(62)
34(70)
47(72)
46(65)
60(81)
65(73)
59(80)
56(62)
50(54)
57(58)
61(60)
1(27)
2(16)
11(6)
28(60)
48(55)
● PREDOMINANTLY MATURE SALMON
▲ PREDOMINANTLY IMMATURE SALMON

FIGURE 25. Percentage of samples classified western Alaskan type—July, 1960. First number indicates sample number; second number percent western Alaskan type.

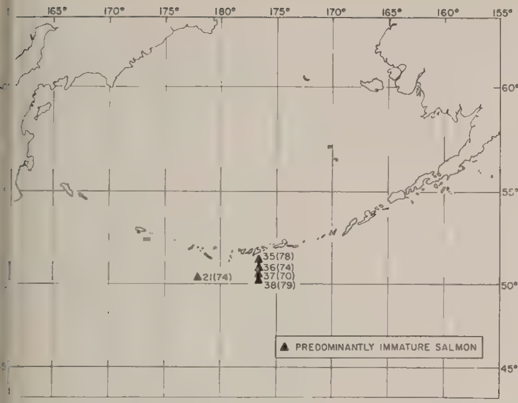
West of 175°03′E. longitude, Kamchatkan morphotype were indicated to dominate all nine samples Kamchatkan morphotype totally dominated sample 3 and 4, and the remaining seven samples containe from 60 to 88 percent Kamchatkan morphotype Samples 18 and 19 which contained a large proportio of immature salmon were estimated as 28 and 2 percent Bristol Bay morphotype respectively.

July.—Twenty-four samples were taken in July, al north of 49° North latitude (Fig. 25). All sample were composed predominantly of immature salmo with the exception of sample 67 at the eastern extreme and samples 1, 2 and 5 at the western extrem of sampling.

The latter three samples were classified as 27, 1 and 10 percent Bristol Bay morphotype. From tim and area of capture, under the tacit assumption "homing", the mature portion of these sample must have been Kamchatkan salmon. As indicate previously, sample 2 was included in the estimatio of the average error of misclassification for Kamchatka, but samples 1 and 5 were not. Sample was small and sample 5 was taken east of 165°I longitude. The possibility exists that the valu obtained were the result of sampling variation, bu this cannot be adequately evaluated for lack of r petitive sampling in this region.

Judging from time of sampling (July 25) samp 67 probably fails to satisfy our basic assumption th only Kamchatkan and Bristol Bay salmon occur in tl regions under study. The major portion of the ru had entered the streams of Bristol Bay and Kamchatl before this sample was taken. Therefore, this samp is considered to contain red salmon from Nor American areas other than Bristol Bay which ha been shown by past analyses to misclassify in co siderable proportion as Kamchatkan red salm (Fukuhara *et al.*, 1959).

In all but two of the samples composed chiefly immatures, Bristol Bay morphotype is found in t majority. This predominance tends to be mc pronounced in the samples obtained closest to t Aleutian Islands. As in previous years, the mark dominance of either continental stock that is appare in most samples of matures is not seen in most sa ples of immatures. This situation may arise as consequence of improper weighting of the functi when applied to immatures. Intermingling Kamchatkan and Bristol Bay immatures may occ or Bristol Bay stocks may be intermingled with salmon from other North American areas.



URE 26. Percentage of samples classified western Alaskan type—August, 1960. First number indicates sample number; second number percent western Alaskan type.

gust.—Only five samples were utilized from the ust collection, all of which were obtained in the ral Aleutian region with four of these taken in ther narrow band along 176°30′W. longitude Fig. 26). The point estimates of Bristol Bay photype in these samples ranged from 70 to 79 ent.

UMMARY AND CONCLUSIONS OF CLASSIFICATION ANALYSIS

The 1960 high seas samples were classified as g of Kamchatkan or Bristol Bay origin using the riminant function constructed on the basis of the 6 collections but with the average error of misclassation of Bristol Bay salmon weighted by the tive abundance of the component stocks based the 1960 escapement estimates.

In the light of a very large run of red salmon Bristol Bay, it was expected that large areas in ocean, particularly the Bering Sea east of 180° gitude, would be almost completely dominated by ure Bristol Bay red salmon. In agreement with expectation, all samples taken east of 180° gitude showed an overwhelming dominance of stol Bay morphotype (average point estimate ater than 90 percent) with the upper 90 percent fidence limit averaging about 104 percent and lower limit averaging about 79 percent.

In the North Pacific Ocean in May and June g. 24) mature Bristol Bay red salmon predominated t of 179°59′E. longitude by percentages ranging n 59 to 100 percent. West of 172° E. longitude mchatkan red salmon predominated by percentages ranging from 60 to 100 percent in samples of mainly mature salmon.

4. The general trends in the east-west distribution of Kamchatkan and Bristol Bay stocks in both the Bering Sea and North Pacific Ocean are similar for the years 1956 through 1960. To illustrate this the average percentages of western Alaska morphotype in samples taken in the high seas in May and June of 1956 through 1960 are plotted in Figure 27 in five degree intervals of longitude.

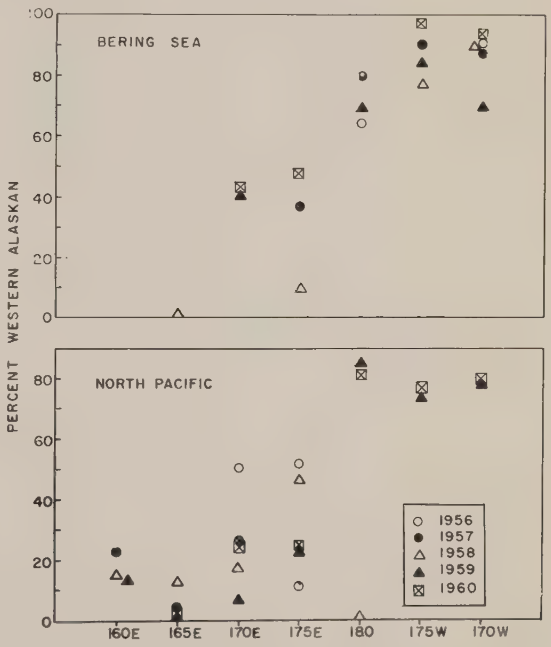


FIGURE 27. Average percentages of western Alaska morphotype in samples taken in the Bering Sea and North Pacific Ocean in late May and June, 1956–1960.

5. Bristol Bay morphotype dominated all samples of immatures to 172°50′E. longitude in July and August. As in past years, the degree to which Bristol Bay red salmon dominate is not as pronounced in immature samples as in samples dominated by matures. This may be attributable to the fact that when sampling takes place, the matures could be more segregated during migration. A further possible explanation may be that given in item 6.

6. It was assumed in this (and previous classification analyses) that only Bristol Bay and Kamchatkan red salmon occur in the Bering Sea and North Pacific Ocean west of the Alaskan Peninsula. This assumption has been tenably justified for maturing salmon but not for immatures. Although there has been little evidence to negate the hypothesis for

immatures, there is a distinct possibility that red salmon from North American areas other than Bristol Bay may occur in the area. Past analyses have shown that using this particular discriminant function, these would be misclassified as Kamchatkan salmon. Alternative analyses must be used to provide information on the origin of these immature stocks prior to interpreting results of immature classification using discriminant function analysis.

7. Deficiencies in sampling are evident in the scarcity of samples from the western Bering Sea and in May and June from the North Pacific Ocean, limiting present knowledge of the distribution in the high seas of Kamchatkan and western Alaskan stocks of red salmon. Although samples containing a predominance of matures taken after certain times can be reasonably used as the Kamchatkan reference morphotypes, the desirability of having stream samples is obvious.

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RED SALMON SCALE STUDIES

by Raymond E. Anas

Red or sockeye salmon are widely distributed in the northern Pacific Ocean. Tagging, parasitological and morphological studies have shown that maturing fish from Asia and North America intermingle in the area north and south of the Aleutian Islands and that the North American red salmon in this area are predominantly from Bristol Bay. The problem to be solved by fishery scientists is to determine the continent of origin of salmon caught on the high seas with a known precision.

Scale studies are one technique that has been used for identifying the continent of origin of salmon taken at sea. Advantages of using scales are that they are relatively inexpensive to collect and process. Various methods employing scales have been developed and show promise of distinguishing Asian from Bristol Bay red salmon. However, the application of scale characters has been questioned owing to inadequate studies, in most cases, of factors that could affect the precision and reliability of continental separation. We have studied some of the factors that could affect precision, and the results of these studies are summarized in this report.

Adequate samples are needed to determine scal character values that are representative of specifi areas. For example, a sample from a Bristol Bay rive could be taken and scale character values could b compared for fish having different ages. If scal character values change depending on the age of th fish, and if this affects its classification as Asian o from Bristol Bay, then fish of each age must be considered separately. As a consequence, larger sampl would be required to determine scale character valu representative of Asian and Bristol Bay fish, becaus each age group would need its own estimate. Fis caught at sea would also need to be considered by ag group; the sampling problem for these is even mo difficult than for the inshore samples.

Scales have ridges or circuli on their surface th are used by biologists to determine how long a fis has lived and also to determine where it was hatche The spacing of the circuli is used to determine th age; the spacing of circuli, number of circuli, sca length, and ratios using circuli counts and sca lengths are used to determine the continent of origi Structurally, salmon scales begin as a small centr

PROPAGATION OF THE COMMON STARFISH, ASTERIAS FORBESI, IN LONG ISLAND SOUND DURING A TWENTY-FIVE YEAR PERIOD.

Victor L. Loosanoff, U. S. Bureau of Commercial Fisheries, Tiburon, California.

Observations covered the period from 1937 to 1961 and were carried in Long Island Sound in the area extending for approximately 30 miles, from Bridgeport to New Haven, Connecticut. The stations, number of which varied from 7 to 23 in different years, were located at the depths ranging from intertidal zone to 100 feet but principally in 12, 20 and 30 feet. Since 1944, locations of 10 basic stations remained the same.

The studies were designed to determine, each year, dates of beginning of setting, daily intensity of setting, end of setting and duration of setting period. Role of several environmental factors in relation to the above-mentioned chronological events and to intensity of setting within the same year and during different years was ascertained to provide, if possible, a basis for predicting time and intensity of setting.

Beginning of setting varied in different years from the last week of June to the last week of July. In 1945, the setting began and ended within the same day, September 11. In other years, it ended between July 23 and September 28. The length of setting period varied from one day in 1945 to 90 days in 1938. The time of peaks of setting also varied greatly from year to year, ranging the first week of July to the middle of August. The heaviest setting occurred in 1938, while in 1945 regardless of a large number of adult starfish present, virtually no setting took place. As a rule, setting was heavier at the 30 foot stations than in more shallow water. Starfish larvae set even at the depth of 100 feet.

No cyclical tendency in starfish setting was established. A good relationship was found between the date setting begins and intensity of set. It showed that a set beginning early may be either poor or good, but a setting beginning late is always poor. Poor sets may end early or fairly late in the season, but good sets never end early. Poor sets tend to be short, good sets tend to be long. Sets which reach a maximum early may end early or fairly late, but sets which reach a maximum late tend to end late.

The intensity of setting may depend upon departure of sunshine from normal for the period between April 16 and July 15. Thus, a sunny spring tends to be followed by a heavier set. Furthermore, if the air temperature during July is above normal, maximum set tends to occur earlier. No other environmental variables were found to have significant relationship with intensity of starfish setting or provide the basis for predicting the date set begins or ends or the duration of setting. Finally, no relationships were found between the number of adult starfish in Long Island Sound and intensity of setting, and between the intensity of starfish and oyster setting during the same years. It is suggested that the presence or absence in the water of specific food organisms and larval diseases and predators may be primarily responsible for the survival, and, therefore, intensity of setting of larval starfish. Local minor water currents may also be important.

Reprinted from Volume 1 of Proceedings of the XVI International Congress of Zoology, Washington, D.C., August 20-27, 1963.

1963

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REARING OF BIVALVE MOLLUSKS

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I. Introduction

Until recently rearing of larvae and juveniles of marine bivalv on a basis where repeatable results could be expected, was virtua impossible because of the lack of satisfactory, reliable methods. Th although culturing of larvae of bivalves was first attempted in the l century, few workers succeeded in rearing them to metamorphosis a as a rule, they were rarely grown beyond early straight-hinge sta Even though, in the twenties, Wells (1927) was able to rear the Americ oyster, *Crassostrea virginica*, from artificially-fertilized eggs to spat, a Prytherch (1924) raised larvae of the same species in large numbe their results could not be consistently repeated by other investigat The failures were usually due to poor culture methods and want good food for the larvae, especially when they were grown in hea concentrations. It is also possible that diseases, including those cau by fungi, were responsible for the persistent failures.

Attempts to rear larvae of bivalves were not confined, of course, *C. virginica*. Cultivation of larvae of several other species was a tried by early workers. For example, Belding (1912) attempted raise larvae of clams, *Mercenaria mercenaria* (formerly *Venus merc aria*), but without success. He concluded that there was no practi method for raising clam larvae to straight-hinge stage because of small size and delicate nature of the egg. Wells (1927), however, more successful and carried the clam larvae in his cultures until th metamorphosed.

Even in more recent years the situation remained practically same. This is well demonstrated by the work of Yoshida (1953) w in his attempts to identify larvae of Japanese bivalves, had to depe upon obtaining the larvae from plankton, instead of trying to grow th from fertilized eggs under controlled laboratory conditions where th identity would be assured. The difficulties experienced as recently 1953 by Nikitin and Turpaeva (1959), in their attempts to raise lar of some bivalves of the Black Sea by using old methods, vouch the inefficiency of these now obsolete approaches.

Obviously, as the general studies of marine organisms progress, necessity for methods by means of which bivalve larvae can be rea successfully becomes more and more urgent. The availability of su methods would immediately offer the opportunity to study the effe of numerous environmental factors, singly and in combination, u the growth of larvae, thus helping to determine the physiologi requirements of these organisms. It would also offer the means studying the genetics of bivalves and initiating properly contro experiments on selective breeding of these mollusks. Moreover, rowing larvae under different conditions their diseases and parasites uld be studied and methods for their control developed. Finally, ecause the larvae of many species of bivalves are much alike in size nd appearance, it was virtually impossible to identify them, with ny degree of accuracy, in plankton collections. With the recent evelopment of methods of rearing larvae in the laboratory, however, his difficulty should soon disappear because larvae found in plankton an now be easily and accurately compared with preserved samples nd photomicrographs of larvae grown from known parents under ontrolled conditions.

By using successfully conditioning and rearing methods, many spects of which were developed at Milford Laboratory (Loosanoff and avis, 1950; Loosanoff, 1954) and are described in this article, larvae f approximately twenty species of bivalves have been cultured at ilford. Not all of these species are indigenous to New England waters r even to our Atlantic coast. Several are native to the Pacific and one pecies came from Europe. The non-indigenous forms were representaives of commercially important species in which we were interested. The bivalves, the larvae of which have been reared from fertilization o metamorphosis, included the transverse arc clam, *Arca transversa*; he ribbed mussel, *Modiolus demissus*; the common mussel, *Mytilus dulis*; the bay scallop, *Pecten irradians*; the jingle shell, *Anomia implex*; the European oyster, *Ostrea edulis*; the native Pacific coast yster, *Ostrea lurida*; the American oyster, *Crassostrea virginica*; the Japanese oyster, *Crassostrea gigas*; Morton's cockle, *Laevicardium mortoni*; the hard shell clam, *Mercenaria* (—*Venus*) *mercenaria*, and its relative, *Mercenaria* (—*Venus*) *campechiensis*; hybrids of these two species; the Japanese clam, *Tapes semidecussata*; the small clam, *Pitar* (—*Callocardia*) *morrhuana*; the rock borer, *Petricola pholadiformis*; the razor clam, *Ensis directus*; the surf clam, *Mactra* (—*Spisula*) *solidissima*; the soft shell clam, *Mya arenaria*; and the common shipworm, *Teredo navalis*.

Of the above species the larvae of *Crassostrea virginica* and *Mercenaria mercenaria* have been studied most intensively and, as a result, we have accumulated an extensive knowledge of their physiological and ecological requirements (Loosanoff and Davis, 1950; Loosanoff *et al.*, 1951; Loosanoff and Davis, 1952a; Loosanoff and Davis, 1952b; Davis, 1953; Loosanoff, 1954; Loosanoff *et al.*, 1955; Davis and Chanley, 1956a; Davis, 1958; Davis and Guillard, 1958; Loosanoff, 1958a; Loosanoff, 1958b; Loosanoff, 1959; and Davis, 1960). Several other species, such as the European oyster, *Ostrea edulis*, and the Olympia oyster, *Ostrea lurida*, have also received much attention.

Most of the other species, however, were studied less intensively, wo on them being confined to culturing their larvae and observing t appearance and general behavior of the latter. Naturally, our knowled of the requirements of larvae of such species is still fragmentary b nevertheless, we shall present the information already available ev though it is admittedly incomplete.

II. Equipment

The rearing of larval and juvenile bivalves requires an adequa supply of sea water of proper salinity and free of substances that m interfere with their normal development. The water used at Milfo Laboratory is pumped from the Wepawaug River at a point abo 100 yd from its entrance into Long Island Sound. Because the tid rise and fall in this area is from 6 to 10 ft, the flushing rate of t comparatively narrow and shallow inlet is relatively high.

The sea water is pumped into a 6 000-gal wooden storage ta located in the laboratory attic. Because pumping normally tak place $1\frac{1}{2}$ hr before and after the high tide stage, the salinity of t water is usually near 27 parts per thousand, which is virtually t same as in Long Island Sound, where the majority of the forms, t larvae of which are described in this article, exists. To assure a supp of water of high salinity the intake of the salt water system is locat approximately 4 ft below the mean low water mark; therefore, it is a safe distance from the surface layers which, after periods of hea rains, may be greatly diluted.

The main pump providing the laboratory with salt water is rubb lined. The intake and distribution lines, as well as the check a cutoff valves, are made of lead. The faucets, however, are of ha rubber. The storage tank is of cypress wood and is painted inside wi asphalt paint.

We prefer lead pipes because, although pipes made of several n plastics are nontoxic, light and inexpensive, they possess seve important disadvantages. One of them is that since it is often necessa to reduce fouling inside of the pipes by treating them with hot wa or steam, this treatment, commonly used with lead pipes, cannot employed in systems containing plastic parts as it may cause dama especially at the joints of the pipeline.

Another serious disadvantage in using plastics is that they adso and absorb many chemicals, including insecticides, and once co taminated can themselves become a source of later contamination the sea water. Moreover, since some plastics are permeable to insec cides and other compounds, these materials might enter from the su ounding soil into pipes carrying sea water. Finally, some laboratories hat have plastic sea water systems have complained that since these ipes are not electrically self-grounded, they present a serious element of danger in laboratories with wet floors.

We are finding an increasing usage for plastic pumps and pipes, specially in our temporary installations. We have also found that tanks made of Fiberglas, instead of wood, can be advantageously used, especially in areas where wood-boring organisms, such as *Teredo*, are common.

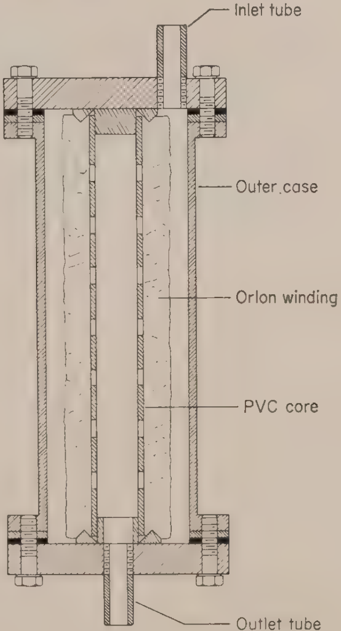


FIG. 1. Diagram of water filter designed to remove all particulate matter larger than 15 μ in diameter. Description in text.

Normally, in addition to small algae on which larval and juvenile mollusks feed, sea water contains many large diatoms, free-swimming crustaceans, gastropods, worms, etc., and their eggs and larvae. Many of these forms compete with bivalve larvae for food, prey on them or may even harbor diseases or parasites that could be transmitted to larvae. We prevent undesirable organisms of larger sizes from entering our larval cultures by filtering the water and later killing the smaller forms with ultraviolet light.

The filter element consists of a polyvinylchloride (PVC) core wound with Orlon. The complete unit (Fig. 1) is manufactured by Commercial Filters Corporation, Melrose, Massachusetts (filter no. CFX1-10-5 with an O15-R10X filter element). These filters, designed to remo all particulate matter larger than 15 μ in diameter, are made wit variety of core and winding materials. We chose the PVC core beca it is nontoxic, and the Orlon winding because it is inexpensive, nonto and does not support bacterial growth.

To prevent fungus diseases in clam larvae and juveniles we beg treating sea water with ultraviolet light in 1954 and, within a short ti had some evidence that such treatment, even of running, unfiltered water, was helpful in preventing mortality of juvenile clams. In t summer of 1955 it was definitely demonstrated that larval cultur receiving treated water and untreated phytoplankton from the outdo mass culture, developed fungus, whereas larval cultures in whi phytoplankton and sea water were both treated did not. Since th time, it has become a routine practice to treat with ultraviolet light sea water used for our larval cultures and for keeping recently- clams and oysters. Moreover, we are attempting to supply ultraviol treated running sea water to all containers in which later stages juvenile clams are grown.

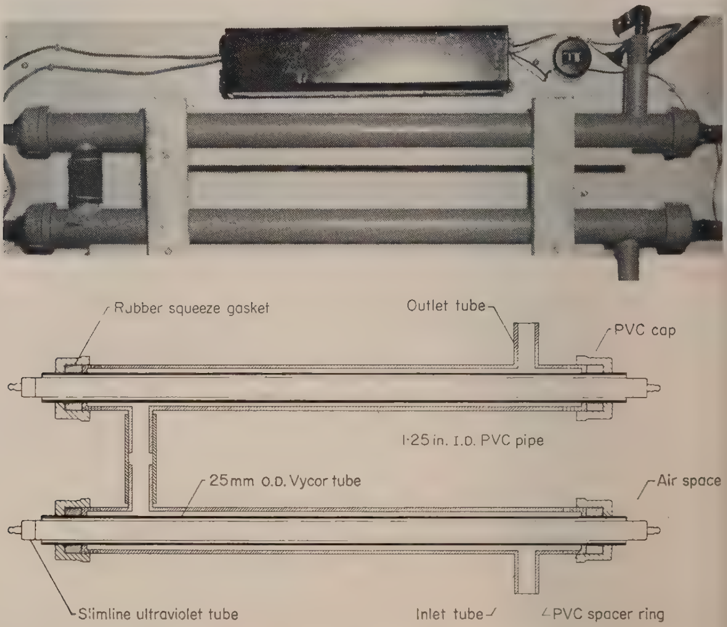


FIG. 2. Photograph (*above*) and drawing (*below*) of ultraviolet water treatment u used at Milford Biological Laboratory. Description in text.

Ultraviolet treatment of sea water for purification of shellfish has een described by several workers in Japan (Sato, 1954; Satoh, 1960) nd Wood (1961) in England. As is the practice in our laboratory, Vaugh (1958) also used ultraviolet-treated sea water for rearing larvae f the European oyster, *O. edulis*. Several of these authors have escribed the equipment used but, because of certain considerations, we constructed our own units, a description of which is offered here.

The ultraviolet water treatment unit consists of a $1\frac{1}{4}$-in inside diameter PVC pipe, 30 in long, threaded at each end for caps (Fig. 2). A small ring of PVC is cut to fit inside of each end of this pipe and reamed to act as a spacer for a 25-mm Vycor tube. A squeeze gasket is used to make a water-tight seal between the Vycor tube and the end of the PVC pipe. An inlet tube is located on the side at one end of the PVC pipe and an outlet tube is located on the opposite side at the other end. The 33-in-long, slimline ultraviolet tube lays free in the $32\frac{1}{4}$-in-long Vycor tube and extends slightly beyond at each end.

In practice we use two such units connected in a series so that the water passes the length of both tubes. Since there is only about a $\frac{1}{8}$-in layer of water surrounding the Vycor tube, this apparatus, when used with filtered sea water, should give practically sterile water at the rate of flow of about 10 gal per min. With unfiltered sea water the efficiency is not expected to be as great, but our experience has shown that even then the treatment is of considerable help in reducing mortality of juvenile clams and in preventing fouling by tunicates, worms and bryozoa.

To condition mollusks for out-of-season spawning it is necessary to keep them in running sea water at temperatures of 18° to 20°C or sometimes higher. Warm sea water is also needed for rearing larvae and juveniles during the cold season. Since the water must not contact toxic metals, conventional water heaters cannot be used. Therefore, to heat the water we use a type of heat exchanger (Loosanoff, 1949). The sea water is heated as it passes through a coil of lead pipe immersed in hot fresh water, which fills the tank of a conventional gas water heater that has had the top removed to permit insertion of the lead coil (Fig. 3). However, because the thermostatic controls of a conventional water heater are not sufficiently accurate, the gas flame is controlled through a solenoid gas valve by a Minneapolis-Honeywell thermostat (T415A323XA3). The thermostat-sensing bulb is encased in a lead well in the warm sea water line and maintains the temperature at 37°C ± 0·5°C.

By mixing varied amounts of cold and heated sea water any temperature between that of the unheated water and 37°C can be main-

tained. In our winter work, when the temperature of the wate
Milford Harbor is near freezing, we often simultaneously emp
streams of water at 5°, 10°, 15°, 20°, 25°, 30°, and even 35 C.
course, any other temperature within this range can also be maintai
by using constant level jars of cold and warm water and regulating

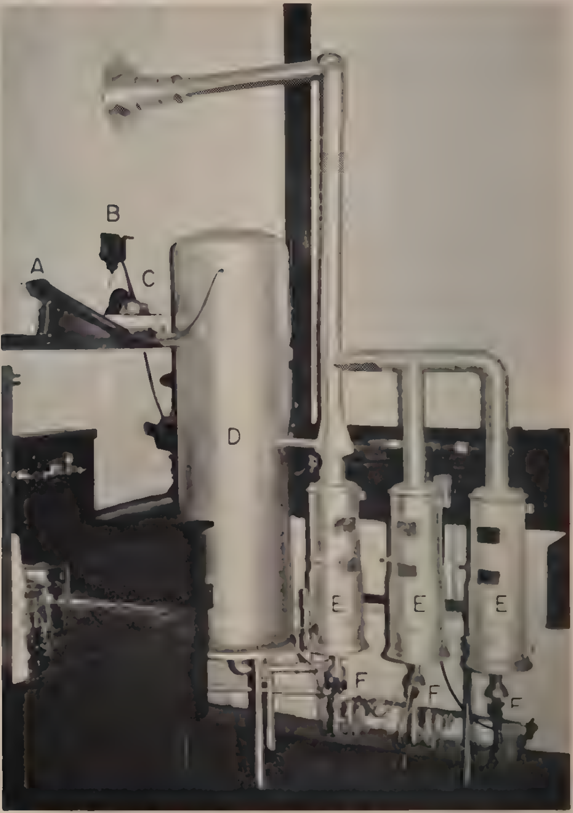


FIG. 3. Heat exchanger to provide laboratory with warm sea water. A, thermos
sensing bulb; B, thermostat; C, air pump to prevent stratification of fresh w
in tank; D, tank; E, gas water heaters; F, solenoid gas valves.

flow from these jars into a mixing chamber from which water of desi
temperature flows into trays or aquaria where experimental anin
are kept (Fig. 4).

To keep larval cultures at desired temperatures various const
temperature devices are used. Since a temperature of about 24 C

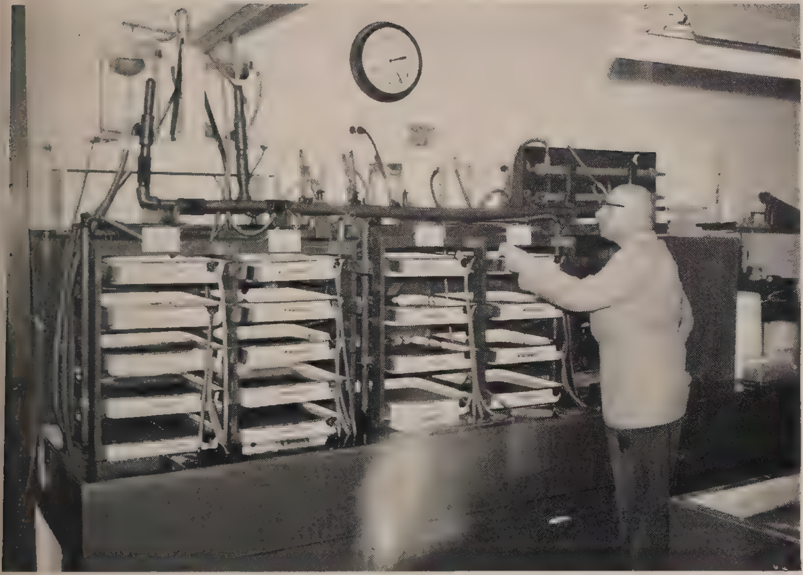


FIG. 4. Racks of trays for conditioning bivalves for spawning. Racks are provided with running sea water of different temperatures. Constant level jars for warm and cold water are seen in upper left corner. Water from these two jars is mixed in required proportions in the smaller glass jars located on lower shelf. Ultraviolet unit for treatment of water is located at right.

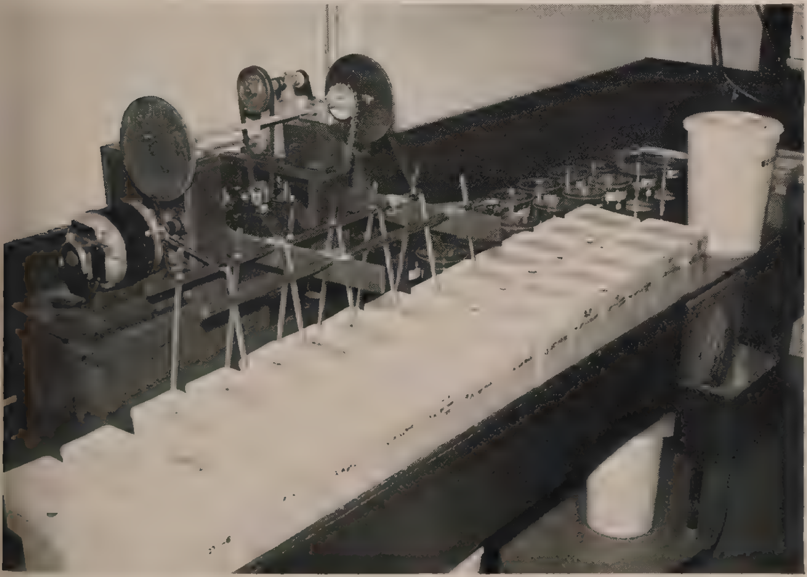


FIG. 5. Constant temperature water bath used to maintain desired temperature in culture vessels, which are partially immersed in water circulating in bath.

near the optimum for growth of algae, such as *Isochrysis galb*
(Ukeles, 1961), which are the best larval foods, this temperature le
is often maintained. However, because 24°C is somewhat above nor
room temperature, our simplest and most commonly used temperat
control devices are lead-lined water tables, 3 ft × 12 ft, that serve
constant temperature water baths (Fig. 5). These tables are filled t
depth of 3 to 4 in with tap water, which is kept in constant circulat
by a pump that takes water at one end of the table and discharge

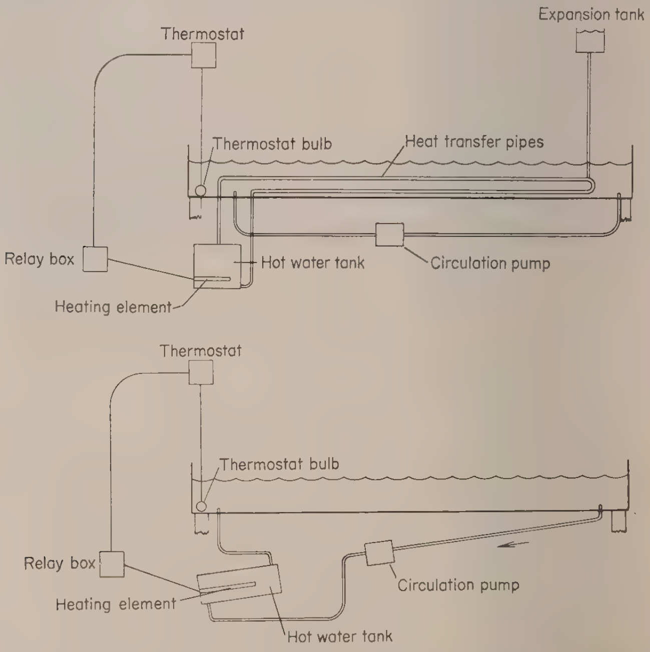

Expansion tank
Thermostat
Thermostat bulb
Heat transfer pipes
Relay box
Hot water tank
Circulation pump
Heating element
Thermostat
Thermostat bulb
Relay box
Heating element
Circulation pump
Hot water tank

FIG. 6. Two methods of heating water for constant temperature baths. Diagra
closed system above, and open system below.

at the other end. A Minneapolis-Honeywell thermostat (T415A323X
with the sensing bulb enclosed in a lead pipe, immersed in the wa
on the table, controls a 1000- or 1500-W immersion heater.
heater may be either inserted in the pipeline, through which the cir
lating pump transfers water from one end of the table to the ot
(open system) or it may be inserted in a small hot water tank and
heat transferred to the water on the table by passage of the wa
from the tank through a lead coil or loop immersed in the water
the table (closed or heat exchange system) (Fig. 6).

Whenever the larval cultures are to be kept at about 24°C any ype of container, the lower part of which is immersed in the bath, ill maintain this temperature because convection currents within essels prevent temperature stratification. Even in containers of different sizes and shapes the temperature will vary only slightly, while in a series of individual containers of the same type the water will be maintained at almost precisely the same temperatures.

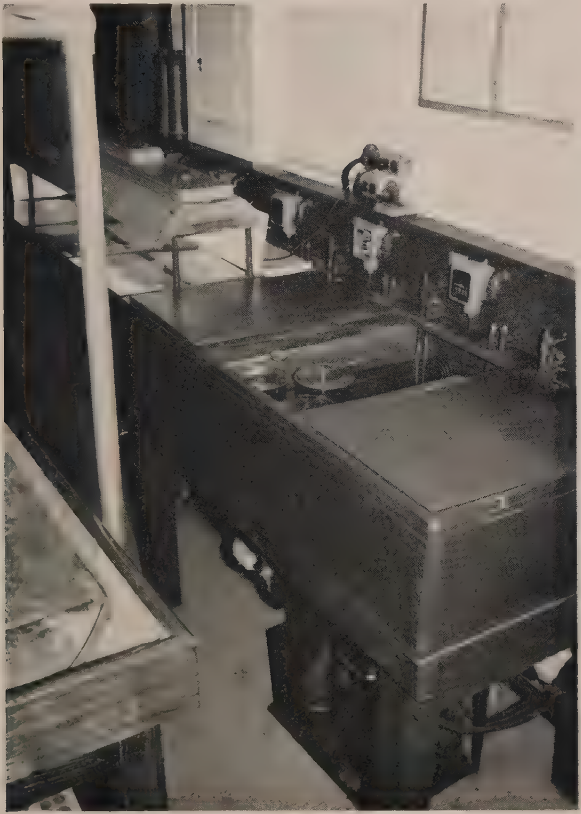


FIG. 7. Constant temperature apparatus consisting of 6 units. Temperature of each unit can be adjusted independently and maintained at any desired level within the range from 5° to 37°C. If necessary, all units may be maintained at the same temperature.

A similar arrangement can be used to maintain temperatures below that of the room by employing a liquid cooler, instead of a heater. Units that combine a heater and cooler and will maint temperatures above or below room temperature are also available. Ho ever, when cooling devices are used it is necessary to keep the wa in cultures continuously agitated to prevent temperature stratificati

To study the effects of different temperatures on development eggs and larvae of bivalves another apparatus was devised (Fig. This apparatus, which can also be used for studies of many ot forms, consists of a series of six lead-lined tanks, each 15 in wide

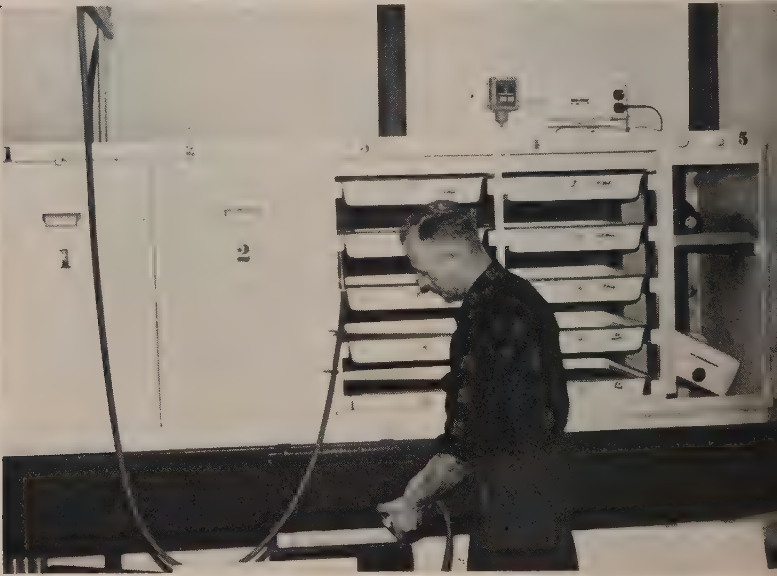
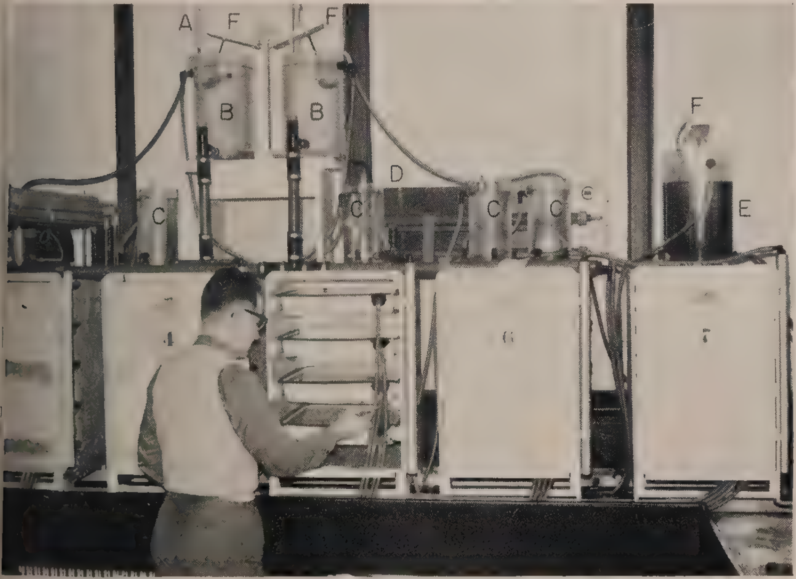


Fig. 8. Constant temperature air chambers in which trays or other containers w larval or juvenile mollusks are held. Electric heater and fan for circulating the can be seen in right hand corner of unit.

26 in long and 13 in deep and filled with fresh water to a desi level. Vessels containing experimental animals are immersed in th tanks.

To maintain water in the tanks at desired temperatures each ta is equipped, along its walls, with loops of tubing to circulate cold a hot water. The amount of water passing through each of these tu is controlled by double-action thermostats which activate solen valves so that if the temperature in any tank falls below the therm stat setting, the valve in the line, through which hot water circulat opens, allowing hot water to flow through the loop. If, on the ot nd. the temperature exceeds that indicated by the thermostat, the enoid valve in the cold water line opens, allowing circulating cold ter to reduce the tank temperature. To have the entire mass of ter at uniform temperature a circulator pump is employed. The nperature controls of the entire unit are so arranged that all tanks y be maintained at the same temperature, within the range from to 37°C or, if necessary, at different temperatures.



IG. 9. Temperature apparatus for simultaneous studies of certain aspects of behavior of juvenile mollusks in running water of different but constant temperatures. A, escape tube for air trapped in sea water lines; B, cold and warm water constant level jars from which water in different proportions enters mixing jars (C). Each jar may be maintained at any temperature ranging from 5° (in winter) to 35°C; D, ultraviolet units through which all sea water passes to constant level jars; E, constant level jars from which phytoplankton is added at a definite rate to running sea water; F, floats controlling levels in constant level jars.

To control the temperature of the air chambers in which culture essels are kept in some experiments thermostatically-controlled elecric heaters are used. For example, in experiments, where a series of our banks of five trays each of standing water are used to hold juvenile lams, a uniform constant temperature is maintained by enclosing all wenty trays in a chamber where thermostatically-controlled electric neaters are installed (Fig. 8). When heated air is used, however,

special precautions are necessary to prevent its stratification.
achieve this in the enclosure where our racks of trays are kept a la
fan forcing air through has been found sufficient.

Still another temperature apparatus is used at our laboratory
simultaneous studies of growth of juvenile mollusks in running wa
of different but constant temperatures (Fig. 9). The entire appara
consists of seven independent units, each insulated so as not to
affected by outside temperatures. As many as five trays may be pla
in each chamber. By mixing, in winter, different proportions of wa
and cold sea water, temperatures ranging from about 5° to 35°C
be maintained quite accurately.

The amount of water entering each tray can be adjusted to
desired rate and, when necessary, the trays in all seven chambers m
receive the same quantity of water and plankton food per hour. A
rule, sea water and food, before entering trays containing juven
mollusks, are passed through the special unit where they are sterili
by ultraviolet rays.

In addition to various apparatus and devices discussed in t
section there are several others that have been used in special stud
A description of these will be given elsewhere.

III. Conditioning Mollusks for Out-of-Season Spawning

Before the present method of providing laboratories with wa
water in winter was developed, experiments on most of the bival
and, especially, their larvae were confined, in New England wat
and similar areas, almost exclusively to the short periods of natu
propagation, usually lasting for only the 2½ or 3 summer mont
However, since it was found that in many bivalves, by using pro
conditioning methods, normal development of gonads can be stimula
and spawning induced during late fall, winter and spring, the exp
mental period has been greatly expanded (Loosanoff, 1945).

Conditioning of bivalves to develop mature gonads during the c
part of the year is relatively simple. It consists of placing mollus
brought from their natural environment where water temperature m
be near freezing, into somewhat warmer water and then gradua
increasing the temperature several degrees each day until the desi
level is reached (Loosanoff and Davis, 1950). Sometimes, especia
towards the spring, instead of a gradual conditioning the mollu
can be placed directly in water of about 20°C. As a rule, the game
obtained from these mollusks were no less viable than from th
conditioned gradually. We have often employed this more ra

proach, thus shortening by several days the length of the con- tioning period which, for oysters kept at 20°C, is approximately 3 to weeks.

The conditioning period can also be shortened by keeping mollusks temperatures higher than 20°C (Loosanoff and Davis, 1952b). For ample, *Crassostrea virginica* kept at 25°C developed ripe spermatozoa nd fertilizable eggs by the 5th day, and light spawning could be duced on the 7th day. When kept at 30°C ripe spermatozoa and rtilizable eggs were found in oysters which, only 3 days before, were ought from the ice-covered harbor where they were hibernating. ome oysters of this group were induced to spawn on the 5th day.

Obtaining spawn from another common bivalve, the hard shell am, *Mercenaria mercenaria*, is also relatively simple in summer. It often accomplished merely by raising the water temperature a few egrees and by adding a sperm suspension (Loosanoff, 1937a). Pre- iously, as already mentioned, this could be accomplished only during short period, whereas, using our recently-developed methods, it is ow possible to obtain ripe gametes and raise larvae of this species n a year-round basis (Loosanoff and Davis, 1950, 1951).

The method for conditioning clams for spawning in winter is the ame as that described for oysters. The entire conditioning period akes approximately 2 to 3 weeks, but can be made even shorter towards r during spring. On several occasions clams brought directly from atural beds during early spring could be induced to spawn without ny preliminary conditioning. However, this method often failed and annot be considered reliable. Usually, only males responded on such ccasions. As a rule, some conditioning of clams is necessary, even owards spring, to have a reliable source of eggs and sperm.

Our studies have demonstrated that bivalves can be conditioned or late fall and early winter spawning only after they recover from the natural spawning activities of the preceding summer. This recovery consists of many complex physiological processes leading, in general, to accumulation of reserve materials, of which glycogen is probably the most important (Loosanoff, 1937a, 1942). Since many species of bivalves of Long Island Sound, including oysters and clams, sometimes continue to spawn until late August or even the middle of September and are not completely recovered from these activities until the end of November, they cannot be conditioned for spawning during these months.

We solved the problem of supplying ripe mollusks during the period from late August to late November by delaying their gonad development and spawning until late fall (Loosanoff and Davis, 1951). Clams, *M. mercenaria*, and oysters, *C. virginica*, are taken from Long Isla Sound early in the season, usually late in May, long before the beginn of their natural spawning, and transplanted to the waters of Mai where the summer temperature averages about 7° lower than in waters. This temperature, while permitting slow development gonads, is, nevertheless, low enough to prevent spawning. Thus, w oysters and clams in Long Island Sound are already spent, th transplanted to Maine still retain their spawn. In the fall, small grou of these mollusks are routinely shipped back to our laboratory, wh they are easily induced to spawn, providing normal gametes which unobtainable locally during that time of the year.

By using the above method spawning of *C. virginica* can be po poned only for 6 or 8 weeks after oysters of Long Island Sound completely spent. After that period the oysters, even if they are s kept in the waters of Maine, begin to resorb undischarged gon material and, thereafter, become useless as spawners. We overca this difficulty by developing another useful method, which postpo early gonad resorption. It consists of conditioning oysters early in spring and spawning them at Milford by early June. After that th are transferred to the colder waters of Maine. Oysters treated in t manner must resorb old gonads and build up glycogen before develop new gonads. Because they are compelled to go through these process these oysters reach ripeness much later in the season than those th are planted in Maine without spring conditioning and spawning an as a result, they do not begin to resorb gonad material as early as unspawned oysters transferred to Maine at the same time. Taki advantage of this situation we have been obtaining normal larvae fro October to January from spawn of oysters so treated.

Because *M. mercenaria* does not resorb undischarged gonad mater in the fall, as oysters do, transferring them to the colder waters of Mai in the spring proved to be a highly satisfactory method of delayi spawning. Under these conditions the clams retain sperm or eg throughout the summer and, as a result, can be induced to spa throughout the next fall, winter and even during the following sprin always producing gametes which develop into normal larvae.

We have also delayed spawning of clams and oysters by taki these mollusks early in the summer from their natural habitat a keeping them in insulated boxes through which mechanically-cool sea water flowed. Usually, only a comparatively small number adult mollusks could be conveniently kept under these conditio and, as a rule, bivalves so treated were in much poorer condition th those kept under natural surroundings in the waters of Maine. Mo er, a failure of the artificial refrigeration system may cause the tire stock to spawn prematurely.

By combining our two methods, one consisting of conditioning llusks for spawning during the cold periods and the other of delaying nad development and preventing spawning during their normal roductive season, ripe bivalves may now be available throughout e entire year.

We have also found (Loosanoff and Davis, 1952a) that *C. virginica* d *M. mercenaria* are able to reproduce several times a year, provided at changes in ecological conditions, especially temperature, are so ntrolled that these mollusks can rapidly recover from spawning, cumulate in their bodies material needed for gonad development, d begin the cycle again. As a result of the discovery of these new proaches and methods, as much can now be accomplished in one year certain fields of the biology of bivalves as could formerly be done three or four.

It should be emphasized that our conditioning methods are not ually successful or applicable to all groups of oysters, *C. virginica*, d, perhaps, certain other species of bivalves of our Atlantic and Gulf asts. This is probably because populations of these species are not netically homogeneous, but consist of different physiological races. e began to suspect the existence of such races in *C. virginica* as early 1937 (Loosanoff and Engle, 1942). Stauber (1950), in reviewing e literature on spawning of the American oyster, also came to the nclusion that oysters from different areas along our Atlantic coast ay belong to different geographical races. Our experiments in this ld strongly supported this assumption by demonstrating that, even ough all these oysters belong to the same species, the temperature quirements for gonad development and spawning of the northern opulations are definitely lower than those of the southern groups Loosanoff and Nomejko, 1951).

The results of our later, more extensive studies, in which several housand specimens representing populations of different areas of the yster-producing belt extending from the Gulf of Mexico to Cape Cod ere used, fully supported our original conclusions (Loosanoff, 1958a). he oysters used in these experiments and observations were from lorida (Gulf of Mexico), South Carolina, Virginia, New Jersey and ew England. They were received in the fall, after they had completely pawned in their native environment, and were kept in Milford Harbor hroughout early winter. Some time in January the first groups of hese oysters were transferred to the laboratory to be conditioned for pawning.

We employed two criteria to evaluate ripeness of the oysters. T first was to ascertain the number of days needed for 50% of the oyst constituting a sample to develop active spermatozoa or fertilizable eg Secondly, we had to determine the length of the conditioning per before spawning in 50% of the oysters could be induced by our us method. Each sample contained fifty adult individuals.

The experiments showed conclusively that Long Island Sou oysters develop gonads and can be induced to spawn after considera shorter conditioning periods than those required by southern oyste When kept at the same temperatures oysters from New Jers although slower than those of Long Island Sound, showed, neverthele much faster gonad development than oysters of Virginia, Sou Carolina and Florida. In averaging the results of the experiments was found that 50% of Long Island Sound oysters, conditioned 21°, 24° and 27°C, contained mature gametes after only 15, 8 and 5 da respectively. The corresponding groups of New Jersey oysters reach this stage only after 55, 32 and 22 days, thus requiring three or fo times as long at the three above-mentioned temperatures as did t northern race.

In certain experiments we were able to induce spawning in 50% Long Island Sound oysters after only 18 days of conditioning at 21 To achieve the same results with New Jersey oysters 78 days w needed. The more southern groups kept under the same conditio failed, as a rule, to produce 50% spawners.

The most striking differences were noticed when oysters of differe geographical regions were kept at relatively low temperatures. F example, after 68 days of conditioning at 12°C, 67% of Long Isla Sound oysters contained mature eggs or spermatozoa. In this gro we were able to induce spawning in one male and, 10 days later, in c female. Oysters of the other groups kept at the same temperatu contained not a single individual with mature gonads, even af 78 days. Moreover, in the majority of New Jersey and Virginia oyst and in all of those from South Carolina and Florida the gonads w so poorly developed that the sexes could not be distinguished, even microscopic examination of the raw gonad material.

The method of inducing spawning of oysters and clams in summ has already been described in detail (Galtsoff, 1930, 1932; Loosano 1937a, 1954). The same method, as a rule, has also been used to indu spawning in other bivalves. In general, our present method can described as follows: After the proper conditioning period ripe bival are placed in glass spawning dishes, each containing approximat 1 liter of sea water of the same temperature as that at which mollus

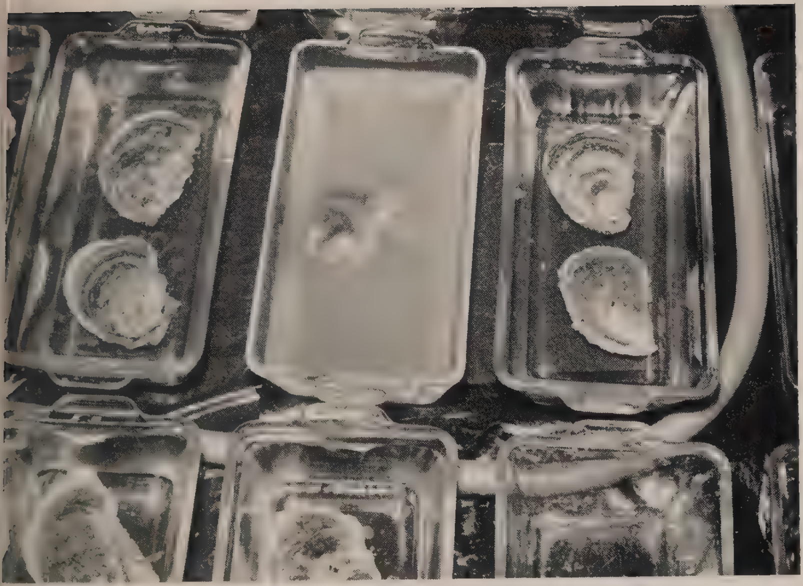


FIG. 10. Ripe oysters in spawning dishes. Male oyster is shown spawning in center dish.

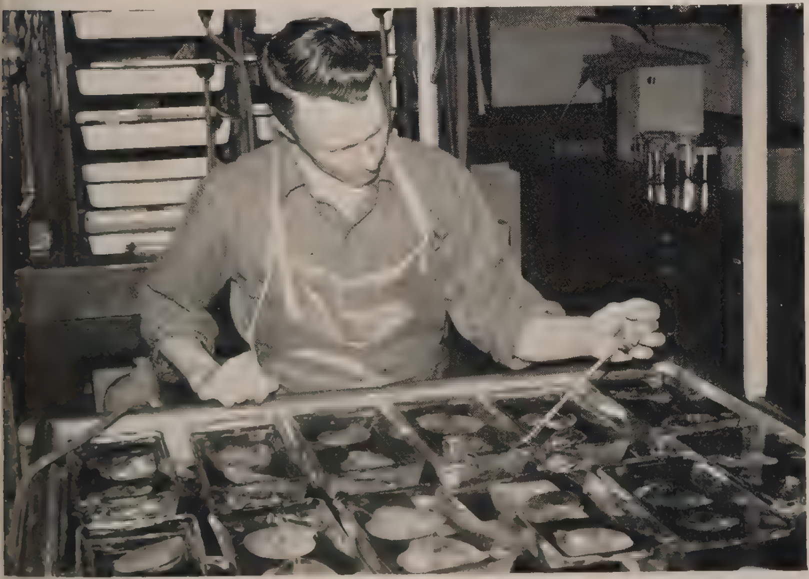


FIG. 11. Inducing spawning of clams, oysters and other bivalves by immersing dishes of sea water containing animals in warm water on spawning table.

were conditioned (Fig. 10). These dishes are partly immersed in large tray or sink, which is filled with hot water, thus quickly raising t temperature in the dishes to the desired level (Fig. 11).

In some instances thermostimulation alone is sufficient to indu spawning. In other cases, however, mollusks need additional stimul tion, which consists of adding to the water small quantities of sper or egg suspension made from gonadal material of ripe individuals of t same species. Many forms quickly respond to combined thermal a chemical stimuli; others, such as the common mussel, *Mytilus eduli* do not usually respond to this method but can, nevertheless, induced to spawn by other means, which will be discussed later.

In a special series of experiments we tried to cause artificial dischar of reproductive elements by injecting weak solutions of Mn_4OH a other chemicals into the bodies of bivalves that could not be spawne by other means. The results were usually not gratifying, except in t case of *M. edulis*, when injection was made in its adductor muscl

At the time of our experiments to induce spawning in ripe bivalv we were already aware of the success of Japanese workers in induci spawning in mussels by giving them a mild electric shock. We repeate these experiments but, unfortunately, with indifferent results.

In still other species, for example, *Modiolus demissus*, all o methods, including those that were successful in the case of *Mytil edulis*, proved to be ineffective in inducing spawning. Therefore, unle ribbed mussels spawn naturally, thus providing normally fertiliz eggs, no other means, except perhaps stripping, are left for obtaini their spawn.

Fertilizable eggs of many species, including those of *C. virgini* (Brooks, 1880), can be obtained by stripping mature females bu since many of these forms spawn so readily in response to chemic and thermal stimulations, it is seldom necessary to resort to this mean However, when working with other species, especially those th cannot be spawned by conventional methods, stripping may be t only way to obtain ripe eggs. It is a simple process and is carried as follows: After removing the outer membrane that covers the gonad the mollusk is gently rinsed in sea water. This action separates fro the gonad large numbers of eggs without serious injury to the Using a series of sieves of proper size mesh the eggs are later freed blood cells, pieces of tissue, etc., and then placed in sea water to whi sperm is added. The fertilized eggs can then be placed in cultu vessels.

This approach is possible only for eggs of those forms in which t germinal vesicle dissolves after stripping. In many species, howeve ncluding *Mercenaria mercenaria* and *Pitar morrhuana*, attempts to rtilize stripped eggs usually fail because in these eggs the germinal esicles remain intact and, as a result, fertilization does not occur. nder normal conditions the germinal vesicles in eggs of such species issolve while they are still in the ovaries of the female, just before hey are discharged in the process of spawning. Upon dissolution of he germinal vesicle the germinal spindle is formed and the discharged gg is ready for fertilization (Loosanoff, 1953).

Recently, following the suggestion of Mr. David Tranter of Australia, ve used a weak solution of ammonium hydroxide to break the germinal esicle of eggs of certain bivalves. By employing this method we ucceeded in raising normal larvae from eggs stripped from *Mercenaria nercenaria*, *Tapes semidecussata* and several other species.

After the eggs were washed from a gonad they were passed through coarse, 50-mesh screen to remove debris, large pieces of tissue, etc. ater, they were washed on a 325-mesh screen which retained the eggs ut let pass the body fluids that might pollute the water in culture essels. After that, 3 ml of 0·1 normal solution of ammonium hydroxde were added to every 100 ml of the prepared suspension of eggs in ea water. After the eggs were in this solution for some time they vere washed again on a 325-mesh screen, being finally ready for ertilization. A more detailed description of handling fertilized eggs will be given in the section on methods of cultivation of eggs and larvae.

The length of exposure to the solution of ammonium hydroxide may vary somewhat from species to species. The following table shows the ratio between length of exposure and percentage of normally developing eggs of *M. mercenaria*:

15 minutes—32%
30 minutes—16%
45 minutes— 9%
60 minutes— 3%
75 minutes— 2%
90 minutes— 0%

Even after 90 minutes of exposure to the solution of ammonium hydroxide some eggs became fertilized, but their development was not normal.

The percentage of normal larvae obtained from chemically-treated eggs was low compared to that of naturally spawned eggs but, nevertheless, it was high enough to permit successful culturing of larvae of those species in which we were not able to induce spawning. Perhaps by changing the concentration of ammonium hydroxide, using other chemical agents, or by improving the methods of stripping even bet results may be obtained.

Finally, there were several species of bivalves which we cou neither spawn artificially nor collect their normally discharged eg Moreover, eggs stripped from some of these forms could not be fertiliz regardless of various preparatory measures, which included t chemical treatment described above.

Fecundity of many lamellibranchs, especially those of commerc importance, has been speculated upon for a long time. Brooks (18 estimated that *C. virginica* could produce between 18 750 000 a 125 000 000 eggs. He based his estimate upon volume of mater removed from the ripe female, but stated that this figure should reduced by approximately 50% because of other matter that w measured together with eggs. Churchill (1920) stated that a lar oyster may discharge 60 million eggs, while Galtsoff (1930) estimat that the number of eggs released in a single spawning may ran between 15 and 115 million. He concluded that the maximu number of eggs that can be released by a single female during t entire spawning season is approximately half a billion. Burkenro (1947), without offering any experimental observations of his ow suggested that Galtsoff's estimate was approximately ten times t high. Belding (1912) estimated that *M. mercenaria*, 2½ in long, produc an average of 2 million eggs, a figure not substantiated by experimen studies.

Since reliable information on the fecundity of even the most co monly studied pelecypods was unavailable, experiments were unde taken by Davis and Chanley (1956b) to determine total numbers eggs actually produced by individual oysters, *C. virginica*, and clam *M. mercenaria*, under natural and artificial conditions.

The first series of observations was made on seventy-five oyste measuring from 3½ to 4½ in long, and on the same number of cla approximately 3 to 4 in long.

The experiments were conducted in the laboratory during the wi ter, a most convenient period for proper conditioning of both cla and oysters. Each bivalve was individually numbered and a comple record was kept of its behavior during the entire experiment. The fi group of oysters composed of twenty-five individuals was spawned 3-day intervals, the second group at 5-day intervals and the thi at 7-day intervals. In clams, which were also divided into three grou of twenty-five individuals each, spawning was induced at 3-, 7- a 14-day intervals. Spawning of these groups of clams and oysters w continued at the specified intervals for more than 2 months.

Experiments have shown that, as a rule, an individual oyster or am does not discharge all its eggs or sperm in a single spawning, but ill continue to spawn at intervals over extended periods. One female yster spawned on sixteen occasions and a clam, eleven times. The umber of spawnings per female oyster ranged from two to sixteen. he highest number of eggs was produced by an oyster that spawned ine times, while a female that spawned sixteen times ranked second. he lowest total number of eggs released by an oyster was by an ndividual that was induced to spawn seven times.

No significant difference was observed in the average number of ggs released during the entire experimental period, whether the oysters ere induced to spawn at 3-, 5- or 7-day intervals, although the verage number of spawnings per female oyster decreased progressively as the intervals between spawnings were increased. It was lso determined that female oysters having larger numbers of eggs ended to spawn more frequently than did females with smaller umbers.

The highest number of eggs released by any female clam in a single spawning was 24·3 million and the total number released by ndividual clams during the entire experimental period of about 2 months ranged from 8 million to 39·5 million, with an average of about 24·6 million.

There was no significant difference in the average number of eggs released in a season, whether the clams were spawned at 3-, 7- or 14-day intervals. It was also found that correlation between the number of times a female clam spawned and the number of eggs produced was not significantly different from zero.

An auxiliary experiment consisted of observations on spawning of fifty oysters taken from Milford Harbor early in April, brought into the laboratory and placed in conditioning trays at temperatures of about 20°C. Three weeks later these oysters were induced to spawn daily for 5 consecutive days, and seventeen females and twenty-four males responded during the first day. Altogether, this group contained twenty-four females and twenty-six males. Of the twenty-four females, fourteen spawned on 2 or more consecutive days, eight spawned on 3 or more consecutive days, five spawned on 4 or more consecutive days, and three females spawned on each of the 5 days of the experiment. Eight males spawned each day.

The important contribution of this experiment was the clear-cut demonstration that there is no 2- to 5-day refractory period during which female oysters cannot be induced to spawn, as maintained by Galtsoff (1930). On the contrary, the results suggest that upon proper stimulation both male and female oysters can spawn any time th have physiologically-ripe sex cells to discharge.

The final experiment consisted of observations on nine fem oysters developing gonads under normal conditions in Long Isla Sound and induced to spawn at the end of June. The total numb of eggs discharged by these oysters ranged from 23·2 million to 8 million and averaged 54·1 million eggs per female. Thus, both avera number of eggs and maximum number per female of the summ

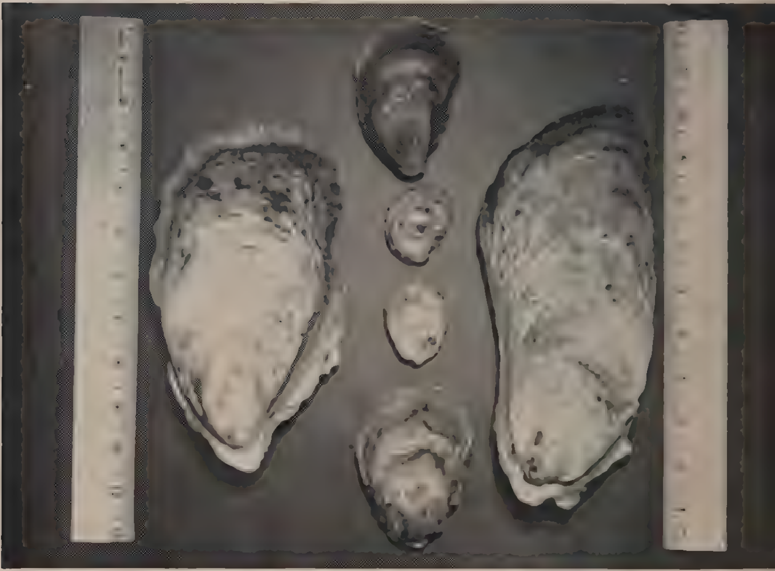


FIG. 12. Representatives of three groups of oysters of different ages and sizes u in studies to determine viability of their gametes. Members of oldest group w estimated to be between 30 and 40 years.

spawning group were about 20 million higher than found in the wint experiment. Nevertheless, none of these oysters discharged as ma as half a billion eggs, as suggested by Galtsoff (1930). The larg number of eggs developed by oysters of this group, as compared wi production of eggs by oysters conditioned in the laboratory duri early winter, may be ascribed to larger reserves of glycogen possess by oysters developing gonads under natural conditions.

A question that had long been of interest to biologists was, At wh age do oysters and clams produce the best, most viable sexual product Until recently, no answer could be given because no reliable metho re available to conduct critical experiments on development of eggs d growth of larvae to setting or post-setting stage. Since develop- ent of these methods, such studies have become possible and recently ere undertaken at our laboratory.

Three groups of oysters of different ages and sizes were conditioned r spawning (Fig. 12). The average age of individuals of the oldest oup was estimated to be between 30 and 40 years, some of them being er 9 in long and over 4 in wide. The intermediate group of oysters marketable size was from 5 to 7 years old, while the youngest group as composed of small oysters approximately 2 years old. These groups ere conditioned and induced to spawn under controlled conditions, eir larvae grown to setting stage, and rates of survival and growth f larvae from the three size groups compared.

The results showed no significant difference between oysters of e different age groups in the time needed to develop ripe gonads. e were somewhat surprised, however, to find that oysters of the oldest roup responded to spawning stimuli more rapidly than individuals f the two younger groups.

There was also no significant difference in percentage of fertilizable ggs because almost 100% of the eggs of all three groups became rtilized. Furthermore, the percentage of fertilized eggs developing o straight-hinge larval stage showed no consistent variation that could e ascribed to size or age of parent oysters. Finally, no consistent ifference was found either in the sizes of the early straight-hinge rvae originating from eggs of different age-group oysters or in urvival and rate of growth of their larvae.

Similar studies on hard shell clams, *M. mercenaria*, measuring from 7 to 110 mm in length, also showed that there was no significant ifference in viability of spawn produced by clams of different sizes nd ages. Often the differences between the progeny of individuals f the same size groups were as great as the differences between those f different ages and sizes. Larvae grown from eggs of clams of all hree sizes were successfully carried to setting stage.

On the basis of the above-described experiments we came to the onclusion that since there was no significant difference in the quality f spawn developed by individuals of different ages or sizes, mature ysters and clams of all age groups may be safely used as spawners.

Of special biological interest was the observation that the sexes mong the oldest oysters were about evenly divided. This discovery as contrary to the old conception that in the oldest groups females hould decidedly predominate in numbers. We also noticed that many f the largest and oldest oysters, while kept in the laboratory to be conditioned for spawning, formed normal, new shell growth, t indicating that even at that age and size the oysters did not lose t ability to grow (Fig. 12).

IV. Cultivation of Eggs and Larvae of Bivalves

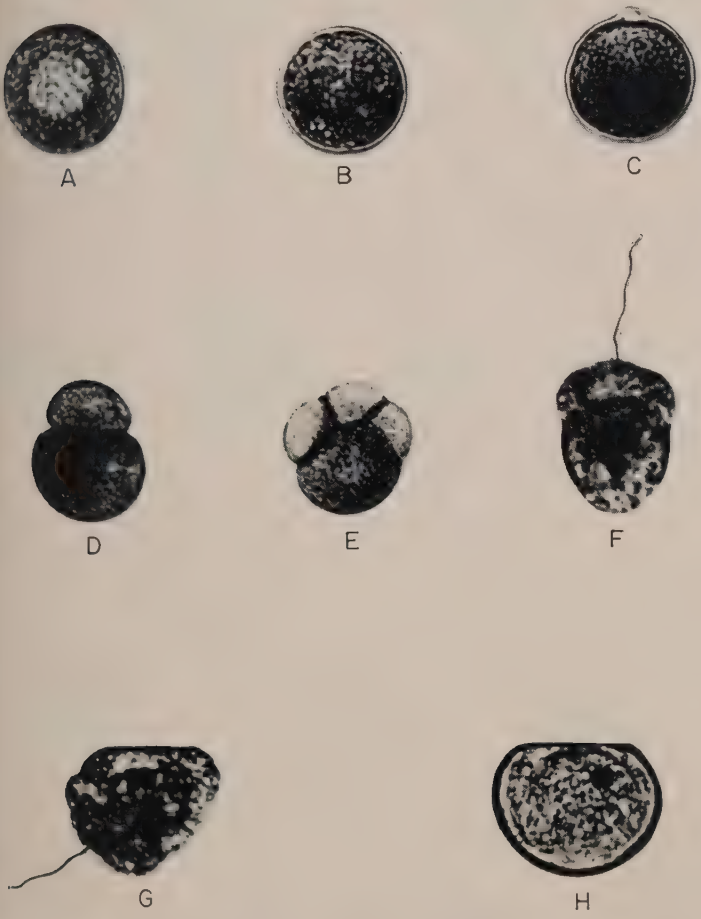
A. *General description of the development*

Eggs of bivalves differ in many respects, including their size, c and specific gravity. They also differ in thickness of the membr surrounding them (Costello *et al.*, 1957). In oysters and certain ot forms this membrane is only a few microns thick. In others, howe such as *M. mercenaria*, the egg proper measures only 70 to 73 μ, w the total diameter of the egg and surrounding gelatinous membr is about 170 μ. This membrane, in many instances, continues to s round the embryo past blastula stage and, on some occasions, u late trochophore stage is reached (Loosanoff and Davis, 1950).

We shall describe specific characteristics of the eggs later when discussing each of the species studied. Here, because the desc tion of a typical bivalve egg and its development to straight-hi stage or, as it is often called, early veliger has been given on ma occasions, including Brooks (1880), MacBride (1914) and others, we s present only a general picture of changes occurring from the mom the egg is discharged, or stripped, until it becomes a straight-hi larva. This description is based upon observations made on eggs early embryos of *Mactra* (= *Spisula*) *solidissima*, the surf clam, whic the largest bivalve of our Atlantic coast. It measures up to 7½ in l and can be found in considerable numbers from Labrador to C Hatteras. Additional information on spawning of these clams rearing of their larvae is included in the section dealing with rear of larvae of different species.

The diameter of a mature egg of *M. solidissima* averages 56· (Fig. 13*a*). Costello *et al.* (1957) give the diameter of the unfertili ovum of the same species as ranging between 53 and 56 μ, thus agree with our measurements. According to Cahn (1951), who bases conclusions on the work of the Japanese investigators, Kinoshita Hirano (1934), whose paper was not available to us for consultati the diameter of the egg of a closely related form, *Spisula sachalinen* is only 50 μ. Another group of Japanese workers (Imai *et al.*, 195 studying the same species reports that the diameter of the mat egg of this clam varies from 70 to 75 μ, thus being considerably lar than the size given by Cahn. Jørgensen (1946) states that eggs *Spisula subtruncata* of European waters vary in diameter from to 55 μ.

Early development of the egg of *M. solidissima* is basically the ne as that of many other bivalves. After dissolution of the germinal sicle (Fig. 13*b*) the size and shape of the egg remain the same. If



Mactra (Spisula) solidissima

IG. 13. Development of *Mactra* (= *Spisula*) *solidissima* from unfertilized egg (A) to straight-hinge larva (H). Diameter of egg is about 56 μ, while length of early straight-hinge larva is about 79 μ. Detailed description in text.

he fertilized egg is kept in water of about 20°C, the polar body is ormed in about 45 min (Fig. 13*c*) and the two-cell stage, measuring bout 65 μ along the longest axis, is reached in 90 min (Fig. 13*d*).

Development of the egg of a bivalve, as described above, is typ only of a group in which the germinal vesicle breaks upon discha

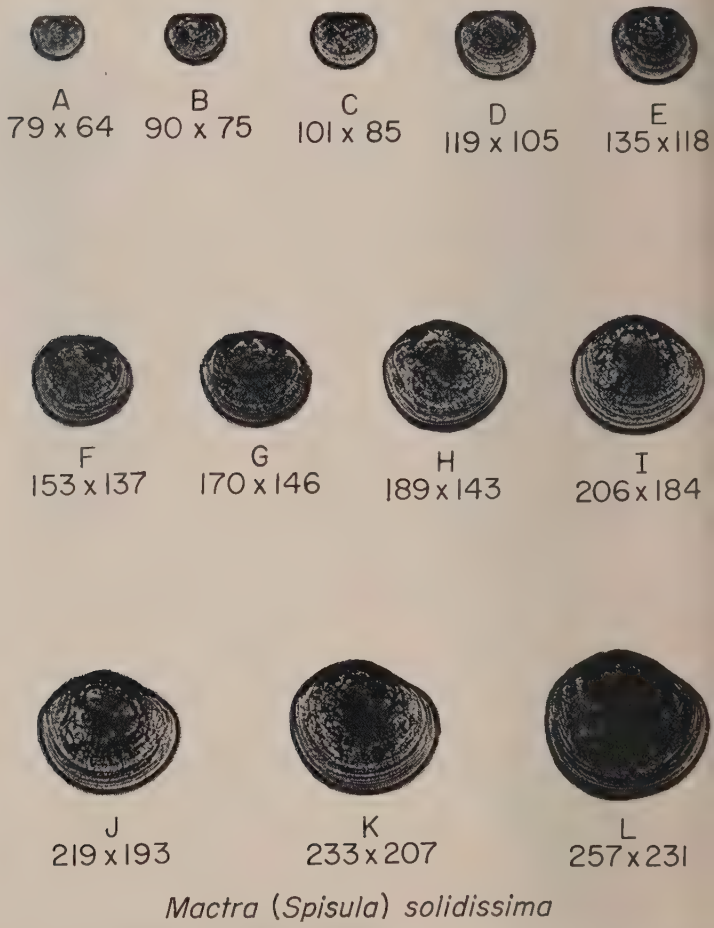

A
79 x 64
B
90 x 75
C
101 x 85
D
119 x 105
E
135 x 118
F
153 x 137
G
170 x 146
H
189 x 143
I
206 x 184
J
219 x 193
K
233 x 207
L
257 x 231
Mactra (Spisula) solidissima

FIG. 14. Development of *Mactra* (= *Spisula*) *solidissima* from straight-hinge stag to metamorphosis (L). Measurements of length and width of larvae of diff stages are given in microns.

or upon stripping, thus rendering the egg ready for fertiliza Eggs of *Crassostrea virginica* and many other species belong to category. In the other group stripped eggs continue to retain t ninal vesicles intact and fertilization does not occur. However, as ady mentioned, eggs of such species can be chemically treated thereby become ready for fertilization.

As cleavage progresses and more micromeres are formed (Fig. 13*e*), embryo gradually develops into a swimming, ciliated larva which ıtually reaches trochophore stage (Fig. 13*f*). Under favorable ditions this stage may be reached in 12 to 16 hr, depending upon original condition of the eggs, culturing methods and, of course, er temperature.

During late trochophore stage (Fig. 13*g*) the cell gland begins to ete the shell. When the shell completely encloses the soft parts larva has reached early straight-hinge stage (Fig. 13*h*).

Development of larvae of *Mactra solidissima,* from early straight- ge stage until metamorphosis, and their length—width measure- ıts during this entire period are shown in Fig. 14. Very early, mal straight-hinge larvae measure only about 79 μ in length and ally between 63 and 65 μ in width. In some cultures, composed stly of abnormal individuals, somewhat smaller, slightly deformed ight-hinge larvae can be seen occasionally, but it is doubtful that y survive to metamorphosis.

Individual larvae of *M. solidissima* display considerable variations to the size at which certain organs of their bodies begin to develop l at which metamorphosis occurs. For example, in some individuals foot can be seen when they are only about 160 μ long. Approxi- tely 80% of the larvae show a well-developed foot by the time y are 215 μ long, and at a length of 240 μ practically all possess s organ.

Disappearance of the velum is another step in larval development t is not strictly correlated with a definite size. In some larvae asuring only 219 μ in length the velum was already completely orbed, while in extreme cases a diminishing, but still functional um was seen in larvae about 257 μ long.

A few larvae begin to metamorphose when they are about 220 μ g, but the majority are between 230 and 250 μ before metamor- osis occurs. At this time the velum is resorbed, rudimentary gills velop, and a powerful ciliated foot, which when expanded is as long the young clam itself, serves as the only means of locomotion. lividuals measuring 262 μ in length were the largest true larvae orded. In this respect our observations are in agreement with those Imai *et al.* (1953), who found that in *Mactra sachalinensis* the foot gins to develop at a length of about 200 μ and that larvae set at out 270 μ.

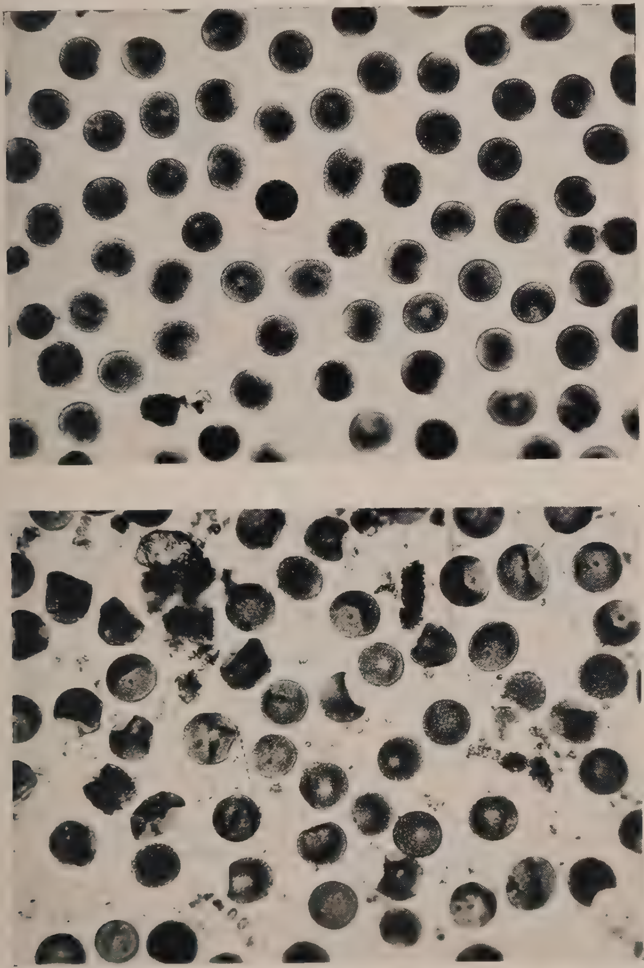
B. *Abnormal eggs and larvae*

Abnormal development of eggs and larvae of bivalve mollusks r be due to any one of a variety of factors or to a combination of s factors. It is our practice, however, to discard cultures in which than 50% of the eggs develop into normal straight-hinge larvae. T is done because batches of eggs giving a low percentage of larvae r be abnormal in some respects, and these abnormalities may lead aberrant experimental results and wrong conclusions. We do know, as yet, what factors are responsible for poor eggs and fe embryos. In some instances abnormal larvae, or failure of eggs develop to straight-hinge larval stage, may be the result of inc patible genetic combinations. Our experience indicates, howe that such combinations are comparatively rare.

Some abnormalities of larvae may be ascribed, no doubt, to poor physical condition of spawners. Several investigators h believed that eggs released late in the season were less viable and duced less vigorous larvae than those from earlier spawnings. Loosa and Davis (1950) were under the impression that the last batche eggs discharged by virtually spent females gave feeble larvae that g slowly and showed high mortality. Cole (1941) offered evidence t the brood strength of *Ostrea edulis* may decline during the course breeding season and he believed that this was due to a depletion food reserves in the bodies of parent mollusks. Walne (1956) thi that the lack of " vigour " in larvae may result from poor condit of the parent oyster and believes it possible that the vigour of lar may be affected by the quantity of food reserves laid down in the e

More recently, Davis and Chanley (1956b) have shown conclusi that the last batches of eggs of both clams, *M. mercenaria*, and oyst *C. virginica*, discharged by virtually spent females were cultured v no apparent diminution of either percentage of eggs developing i straight-hinge larvae or rate of growth of these larvae. Accordin we now believe that abnormal or feeble larvae do not occur m frequently in later spawnings than in other spawnings throughout season. As has already been mentioned, our experiments have sh that there is no correlation between viability of spawn and age parents.

There is evidence that bivalves can be induced, by strong chem and thermal stimulations, to abort eggs even though they are fully ripe (Fig. 15). In some cases such spawnings appear to be q normal and a large number of eggs may be released. More oft however, comparatively few eggs are shed. In the case of *C. virgi* immature oyster eggs usually develop only to late gastrula or e chophore stages, and then become so "sticky" that they adhere each other and to the walls of the containers, particularly at the



IG. 15. Largely normal (*above*) and abnormal (*below*) eggs of *Ensis directus*. Abnormal eggs were discharged by a female compelled by strong stimulation to spawn before eggs were ripe. Normal eggs vary from 64 to 73 μ in diameter.

ir-water-glass interface where they normally congregate in large umbers.

With somewhat more advanced, but still not entirely ripe, oyster

eggs the larvae develop more normally but are quite small, measur
only 60 to 70 μ at the 48-hr stage (Davis, 1949). Finally, in indu
spawning of oysters late in the season after resorption of their gon
has begun, embryonic development of eggs is frequently abnor
and only a low percentage of them develop into healthy straight-hi
larvae.

Subjecting eggs and spermatozoa to temperatures higher than 3
may injure or even kill them. Maintaining recently discharged e
in heavy concentrations, a condition that leads to formation of a th
layer of them on the bottom of rearing vessels, may result in a suffici

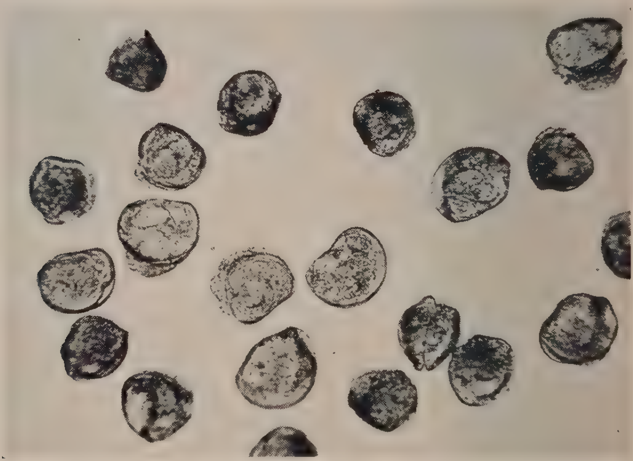


FIG. 16. Abnormal 4-day-old larvae of *Mercenaria mercenaria* from crowded cult
Largest larvae in photomicrograph are approximately 105 μ long.

depletion of oxygen and accumulation of catabolic products that
affect the eggs and their further development. If zygotes and ea
embryos are badly overcrowded, their shell development usua
proceeds only as far as the shell gland stage. Thus, instead of sh
being fully formed 48 hr after fertilization, as occurs in normal lar
which, at that time, can retract their soft bodies completely within
new shell, overcrowded larvae have a small, dark oval area denot
the position of the shell gland or a small band of shell material
more than twice the diameter of the shell gland.

In less-crowded cultures larvae form enough shell to protrude fr
their bodies to give the appearance of small wings (" winged larvae
Under somewhat better conditions a larger, but still incomplete sh

formed, but the hinge line, instead of being straight, is concave, racterizing " saddleback larvae ", or convex, typical of " hump- ck larvae " (Fig. 16). In both of these abnormalities much of the ntral portion of a larva's body will extend beyond the shell. The ults of overcrowding on development and growth of larvae will be ore fully described in a later section of this article.

Occasionally, in some cultures many larvae have abnormally small la. This abnormality may, sometimes, be due to mechanical injuries the velum when larvae are screened before their shells are fully veloped to protect the soft parts. In other cultures it has been sociated with the presence of numerous ciliates. It is possible that lar deformities in these cases were the results of injuries by ciliates, t it is more probable that the ciliates were feeding on particles of la cast off by larvae in response to adverse conditions, such as tificially-created concentrations of certain chemicals.

The same type of abnormalities, as observed in overcrowded ltures, occurs when eggs are cultured in sea water in which adult sters have previously been kept. Probably because of the same ason, eggs carried along with water from tanks or trays in which mass spawning has occurred seldom develop into normal larvae less the original water is greatly diluted with fresh sea water.

Failure of larvae to develop normal shells when overcrowded, or hen grown in water in which adult oysters had previously been kept, ay indicate a depletion of certain substances, normally present in a water, that are needed for shell formation. In experiments devised verify this possibility some of the eggs discharged by a single female ere placed in fresh sea water, while others, fertilized with sperm om the same male, were placed in sea water taken from an aquarium which adult oysters had been kept. The latter group of eggs gave much lower percentage of normal larvae.

One interesting class of abnormal larvae consists of those that do ot feed, even though they do not show clear-cut anatomical malformaons. These apparently normal larvae, which developed to straight-inge stage under our standard conditions and are kept in the same ltures with other larvae which are feeding and growing normally, em unable to feed, do not grow, and eventually die. Before death, e larvae become emaciated so that most of the space inside their ells is empty with only the retractor muscles, a small velum and a runken visceral mass remaining. In some cultures this abnormality found in more than 25% of the larvae.

In several experiments this type of abnormality has been associated ith the kind of food given. In these instances approximately 50%

of larvae of *M. mercenaria* receiving *Chlamydomonas* sp. displa this abnormality, while the remaining 50% fed and grew at a nor rate, as did all of the sibling larvae in other cultures receiving ot foods. A similar phenomenon was observed in American oyster lar fed *Phaeodactylum tricornutum* (Davis and Guillard, 1958).

While some anatomical abnormalities may interfere with ability of larvae to gather or ingest food, resulting in poor gro and eventually death, other abnormalities, such as badly defor shells, may still permit larvae to feed and grow. Sometimes, as t grow, such larvae gradually become more normal in appearance, usually remain distinguishable even when they are nearing metam phosis.

Experiments on tolerance of eggs and larvae of bivalves to s factors as turbidity and salinity, and to chemicals, such as pestici antibiotics, and bacteriostatic compounds, have also shown that any one of these falls outside of the tolerated limits, embryonic devel ment becomes affected, resulting either in death of the zygotes or abnormal larvae. These matters will be discussed in more detail la in the article.

Some of the larvae, particularly those of the clam, *M. mercena* that are abnormal because of overcrowding, exposure to low tempe tures or high turbidity during early stages of development often gr to metamorphosis if returned to favorable conditions and given g food.

Dense algal blooms may also cause abnormal development. have frequently observed, during blooms of dinoflagellates in Milf Harbor, that in our laboratory cultures only a small percentage clam or oyster eggs developed into normal straight-hinge larv Eggs placed in water from which algae were removed by Millip filters showed only a slightly higher rate of normal development t eggs grown in unfiltered water containing dinoflagellates. Eggs fr the same spawnings but cultured in sea water collected prior to bloom gave considerably higher percentages of normal larvae (Da and Chanley, 1956b).

It may be added that plankton samples collected in Long Isla Sound during or immediately following heavy algal blooms are usua characterized by the scarcity or even complete absence of early straig hinge stages of bivalve larvae (Loosanoff, 1958a). We believe t reduction in numbers of normally developing bivalve eggs and lar in the above instances is primarily caused by highly toxic metaboli of algae that may persist for several days after the blooms have end It is possible, however, that this phenomenon is due, at least in p removal by algae of certain chemicals from sea water that are sential to larval development.

C. *Methods of cultivation of eggs and larvae*

Methods of culturing eggs and larvae of bivalves under laboratory d small-scale hatchery conditions have been tested by many workers r over 100 years. Costé, a Frenchman, was probably the first to tempt this around 1858. In the United States a number of extremely pable men, including Brooks (1880), Ryder (1883) and Winslow 884), continued these efforts on *C. virginica*, but were unsuccessful. erhaps the best summary of these efforts is given by Winslow, who ates, " But after my experience of the past spring and summer I am nvinced that it will require a series of painstaking experiments, tending over considerable time and conducted under many dissimilar nditions, before the artificial production and culture of the oyster is ade a matter of practical importance."

Interest in artificial propagation of bivalves was revived when rytherch (1924) and Wells (1920, 1927) succeeded in carrying oyster rvae to metamorphosis. This success was probably due to the practice f renewing the water in which oyster larvae were kept. Wells used a ilk separator for this purpose, while Prytherch used filtros plates. ther successful workers in this field included Hori and Kusakabe 926), Cole (1936), Bruce *et al.* (1940), Lindsay and Woelke (1960), oelke (1960) and, especially, Imai *et al.* (1950b). In our case some ysters were carried to metamorphosis as early as 1932, but efforts o repeat this success usually failed until about 1946–1947 when we egan to develop and improve the methods used at our laboratory Loosanoff and Davis, 1950; Davis, 1953; Loosanoff, 1954).

It is our practice to fertilize eggs as soon as they are discharged. sually it happens automatically because since we use a sperm suspension to stimulate spawning, spermatozoa are already present in he water when females begin to discharge eggs. Fresh, actively-moving perm are used to assure normal fertilization of eggs and development f zygotes. Sufficient quantities of sperm are always added, but when working with small eggs, such as those of *C. virginica*, which cannot e retained even by fine screens, we limit the quantity of suspension. In this way excessive quantities of sperm are not carried into our ulture vessels, and the undesirable effects of decomposing sperm on developing eggs are avoided.

The bivalves are usually spawned in Pyrex glass dishes containing about 1·5 liters of water (Figs. 10 and 11). As has already been mentioned, to separate the eggs from the debris and, later, from the excess sperm, blood cells and body fluids accompanying the spawning, we use a ser of stainless steel sieves with screens containing different numbers meshes per linear inch (Fig. 17). The finest screen that was fou practical in our operation has mesh openings averaging 44 μ, but sin many meshes are actually larger and exceed the diameter of an oyst egg, which is about 50 μ, many eggs pass through the sieve. It true that by using No. 25 bolting silk a smaller size mesh is availa but in that case the openings are so small that they easily get clogge

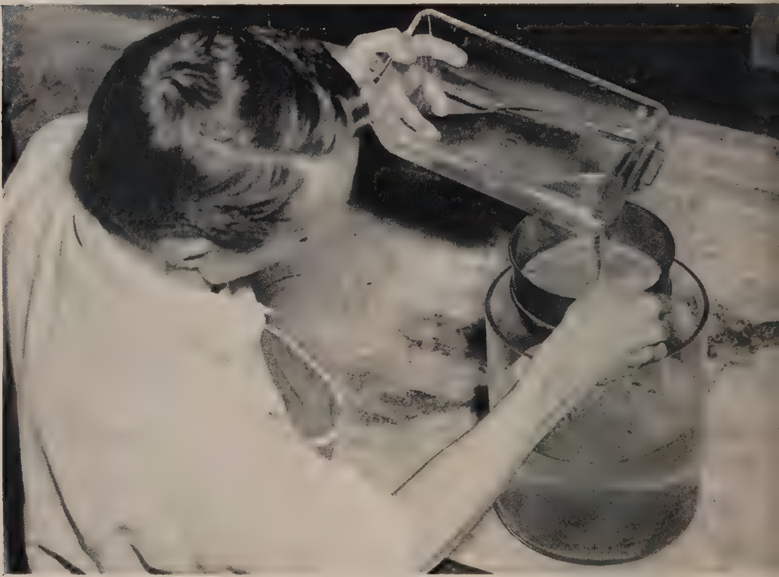


Fig. 17. Screening bivalve eggs through 100-mesh sieve to remove detritus. Simi screens, of 3 in diameter and of smaller mesh opening, are used to collect biva eggs and to retain larvae during changes of sea water in culture vessels.

rendering the sieves useless. As a result, in our practice we use a seri of sieves, the finest of which has a nominal opening of about 44 followed, when necessary, by any of the coarser screens with openin of 53, 62, 74, 88, 120, 125, 149 and 177 μ.

In species having eggs too small to be retained even by our fine screen, the eggs can be partially freed of body fluids, sperm, etc., letting the eggs settle on the bottom of a dish and then syphoning decanting most of the fluid. By repeating this procedure sever times most of the undesirable substances that are dissolved or suspend in the water will be discarded.

We have used a variety of containers to culture larvae. Some of hem were large glass vessels, including Downing and McDonald jars sed in fish hatcheries for incubation of semi-buoyant eggs, lobster rs. 5-gal earthenware jars, and 75-gal polyethylene and Fiberglas ontainers. We have also grown larvae in large, outdoor, concrete anks containing several thousand liters of sea water (Loosanoff, 1954). n all these instances the larvae were grown successfully.

For precise experimental work Pyrex glass beakers of 1000- to 500-ml capacity are perhaps the most satisfactory because they are ot toxic and are readily cleaned and sterilized (Fig. 5). Polyethylene nd other plastic containers are also convenient and non-breakable nd some can be sterilized. However, some of them are permeable to ertain insecticides and, perhaps, to other substances and are known o adsorb a variety of toxins. Because of these considerations polythylene and some other plastic containers, while convenient as culture essels, cannot be used in experiments involving certain toxic substances, such as insecticides.

New, soft glass vessels may contain substances which are toxic o eggs or larvae of oysters and clams. Even though these vessels are conditioned in sea water for several days, culturing larvae in them is always haphazard because, although larvae in different vessels are presumably grown under identical conditions, their rates of growth are often distinctly different and they show mortalities unrelated to the treatment. At the same time sibling larvae grown in earthenware jars or Pyrex glass containers suffer no mortality and different cultures receiving the same treatment show good duplication in their rate of growth.

Although we could not identify the substances responsible for poor growth of larvae grown in soft glass jars, we found, nevertheless, that young bivalve larvae, especially those of *C. virginica*, are sensitive to presence in the water of even minute quantities of certain chemicals. For example, we noticed that washing of glassware and other implements with tap water that passed through a pipeline containing copper unfavorably affected larval development. Apparently, even minute quantities of these metals are sufficient to interfere with normal development of eggs and larvae.

Our experience in growing bivalve larvae has shown that they cannot be kept in recently-built concrete tanks and that, usually, it is necessary to age the tanks with sea water for a long time before this can be done.

Since most of our studies are quantitative, as well as qualitative, definite numbers of eggs or larvae per ml of culture are needed from the start. This is achieved in the following manner: eggs are placed in a tall, narrow glass jar and the water in it is thoroughly agita with a perforated plastic plunger to distribute the eggs uniform A sample is then taken with a volumetric pipette, and the number eggs or larvae per ml is determined by counting them on a Sedgwi Rafter cell. After that the eggs or larvae are again agitated, to ens their even distribution in the vessel, and the necessary volumes water carrying larvae are transferred to culture vessels.

We usually begin our experiments with 10 000 to 15 000 straig hinge larvae per liter of sea water. However, because not all fertili eggs develop into normal larvae, it is our practice to place appro mately twice this number of eggs into each culture vessel to produc sufficient number of larvae. Accordingly, about 30 000 eggs per li are used in starting cultures. These eggs are placed in contain filled with sea water that is first filtered through an Orlon filter a then subjected to the sterilizing action of ultraviolet rays. The e are then left to develop undisturbed for 48 hr and no food is add during this period.

All culture vessels are immersed in a common water bath tab the temperature of which is controlled within ± 1·0°C (Figs. 5 and Usually, neither aeration nor mechanical agitation is employed becau we have established that clean, well-attended cultures do not requ aeration if the water is changed every second day. In special expe ments requiring mechanical agitation we use a number of devic including a rotating wheel, paddle-agitator (Fig. 5), or regular shaki machine.

At the end of 48 hr young larvae, now protected by fully form shells, are collected by screening the cultures through sieves havi 325 meshes per lineal inch (44 μ opening). Larvae retained by t screen are gently washed and placed in a tall jar. Using the sa method as that employed with eggs, the number of larvae per ml determined, and the appropriate volumes of water containing larv are placed in each culture jar to create desired concentrations.

Samples of larvae are taken whenever needed, usually at 2-d intervals. This is again accomplished by collecting all larvae from container on a 325-mesh screen and then transferring them to graduated cylinder of 1-liter capacity from which, after prop agitation, required samples are taken, while the remaining larvae a returned to the culture vessel.

D. *Larval period*

Rate of growth of veligers from straight-hinge stage to me morphosis is affected by many conditions. In our laboratory w e chief controlling factors have been food and temperature. The role these conditions will be more fully discussed in special sections later , and also in the sections dealing with development and growth of rvae of different species; therefore, here it will be sufficient to mention ly general observations.

Our experiments have shown that larvae of different bivalves display fferent food requirements (Loosanoff and Davis, 1951). Until they ach a length of about 125 μ larvae of *C. virginica*, for example, are uite restricted in types of food they can utilize (Davis, 1953). Certain aked flagellates are the only organisms, thus far tested, that may be cluded in this category. *Chlorella* is one of the many genera of algae aving thick cell walls that oyster larvae either cannot utilize or tilize only to a very limited extent during early stages, although it ems to be quite a satisfactory food for older larvae (Davis and uillard, 1958). Thus, if during the early stage of development of yster larvae specific food organisms are either entirely absent or are ncommon, the larval free-swimming period may be greatly prolonged r the larvae may never reach metamorphosis. For example, during ur earlier efforts of raising larvae of *C. virginica*, when little was nown about their food requirements, approximately 50 days were equired before the most advanced individuals began to metamorphose n some cultures. In similar cases, with larvae of *C. gigas*, the cultures vere discarded after 53 days because the largest larvae at the time neasured only about 100 μ. Now, using good food organisms, such as *Isochrysis galbana* and other naked flagellates, and maintaining the temperature at about 23°C, larvae of *C. virginica* have been reared to metamorphosis in our laboratory in 18 days. This is, probably, the approximate time required by larvae to grow to setting size under natural conditions in Long Island Sound (Loosanoff and Engle, 1947). At 30°C well-fed oyster larvae, grown under laboratory conditions, began to metamorphose 10 days after fertilization.

The importance of the second factor, water temperature, on length of larval period of bivalves has also been well demonstrated in our studies of larvae of *M. mercenaria* (Loosanoff *et al.*, 1951). These studies showed that, under identical conditions, larvae kept at a temperature near 30°C began to set as early as the 7th day after fertilization, while cultures maintained at 18°C contained the first metamorphosing individuals only after 16 days.

In the case of larvae of all the species we reared it has been clearly demonstrated that even though larvae originate from the same spawning and, sometimes, from the same parents, and are kept in the same vessel under identical conditions, individuals grow at widely

different rates and, therefore, metamorphose at different times (Fig. 1
For example, in a recent experiment a healthy culture of larvae
C. virginica fed a mixture of *I. galbana* and *Monochrysis lutheri* a
kept at about 23·5°C began to set 18 days after fertilization. Setti
gradually increased in intensity and remained heavy for the fi
17 days, but some larvae continued to swim, before metamorphosi
for another 10 days. Thus, setting of this, presumably, homogeneo
culture continued uninterrupted for a period of 27 days.

A number of similar observations on larvae of *M. mercena*
obtained from the same parents and grown under identical conditio
but showing considerable individual variations in rate of growth and

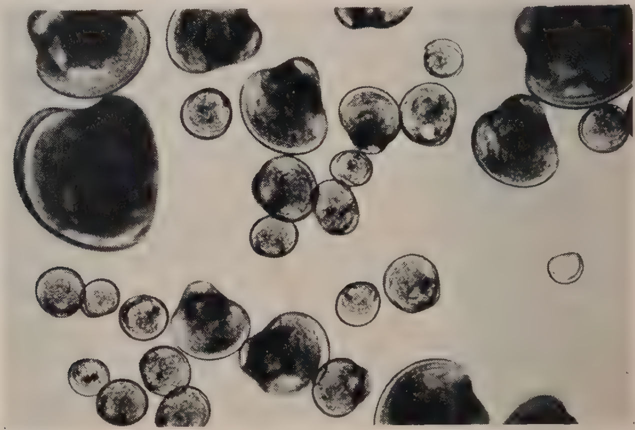


FIG. 18. Differences in sizes of larvae of *Crassostrea virginica* of the same age and gro
under identical conditions in the same culture vessel. Some of the largest larvae
approximately 295 μ long and are nearing metamorphosis.

time needed to reach metamorphosis can be given. Perhaps the m
detailed description of this phenomenon appears in the paper
Loosanoff *et al.* (1951) on growing clam larvae at five constant
different temperatures. These authors gave the minimum and ma
mum sizes of larvae recorded in each culture every 2nd day from ti
of fertilization until the majority of the larvae metamorphosed. Duri
the early life of a culture, on the 2nd or 3rd day, the larvae differed
size by only a few microns, but several days later, depending upon t
temperature, the size ranged from small straight-hinge larvae
approximately 100 μ long to full grown, ready-to-metamorpho
individuals. For example, sizes of larvae grown at 30°C ranged on t
8th day from 107 to 226 μ. In a culture kept at 21°C the minimum a

aximum sizes recorded on the 21st day were 107 and 221 μ. Our lleagues working in the same field, especially Imai *et al.* (1954), lly share our experiences.

At present, no well-based explanation can be advanced for these fferences. Perhaps, as has been suggested in connection with survival d growth of certain fish, vitality of the individual eggs and larvae at emerge from them depends to some extent upon the position of the gs in the ovaries and the amounts of nutritive materials that have en stored in the individual eggs before they are discharged.

Chanley (1955) assumed that differences in sizes of larvae in the me cultures must be due, at least in part, to inherited characteristics. e also reported evidence of significantly different rates of growth of rvae originating from eggs of the same female crossed with different ales and larvae grown from eggs of two females individually crossed ith the same male. He tentatively concluded that inherited differences om either parent may be responsible for differences in rate of growth different larvae.

In some cultures, especially those kept at comparatively high mperatures, the range of larval sizes usually diminishes several days ter beginning of metamorphosis. This is due to the disappearance of rger individuals because of setting and, partly, because abnormal, ndeveloped, slow-growing larvae are rapidly dying.

There were periods in our practice, for example, in growing larvae f *Ostrea edulis*, when regardless of all efforts they would not grow at ll or ceased growing soon after reaching a size of about 220 μ. The asons for cessation of growth still remain an enigma because, at mes, these larvae refused to grow even when given foods on which, n previous experiments, they grew well.

E. *Hardiness of eggs and larvae*

According to Nelson (1921) larvae of *C. virginica* are extremely ensitive to a sudden change in water temperature. A drop of only to 5°C within 24 hr may be followed by the disappearance of a ajority of the larvae. According to the same author rain storms, as ell as strong winds, cause death of large numbers of bivalve larvae. elson, however, failed to offer experimental evidence to support his ontention of the unusual sensitivity of bivalve larvae to relatively inor changes in their environment. Our observations, reported partly n this section and partly in the sections to follow, lead us to disagree ith Nelson's point of view because they have clearly demonstrated hat bivalve eggs and larvae, if protected against disease-causing rganisms and toxic substances, are rather hardy.

Laboratory and field observations lead us to believe that oyster eg
that are still in the ovaries are hardy and capable of withstandi
sharp physical changes in their environment. For example, on seve
occasions oysters with mature gonads have been kept for vario
periods of time in the refrigerator at about 2°C to delay their spawnin
Some of them, kept at this low temperature for 7 days, have spawn
copiously later on, when subjected to proper stimulation, and larvae fr
these spawnings have been reared to metamorphosis. Other grou
kept in the refrigerator for 15 days also spawned normally and p
duced healthy larvae. However, oysters that were kept in the refr
erator for 30 days spawned feebly, and only a portion of the eg
developed into normal larvae. This semifailure was probably due
severe dessication of the oysters and their gonadal tissue. This conc
sion is supported by the observation that the best spawnings occurr
when refrigerated oysters, prior to attempts to spawn them, we
kept in running sea water at room temperature for at least 6
During this recuperation period they probably restored their water lo

Another experiment on effects of low temperature upon ovari
eggs of *C. virginica* of Long Island Sound was performed only la
winter (1961–62). Oysters measuring from 3 to 6 in long were broug
into the laboratory early in January from their natural beds and plac
in conditioning trays to be ripened for spawning. After conditioni
at about 20°C for about 1 month, these oysters, now ripe, were tra
ferred to outdoor tanks where the water temperature was near 0
and where, at times, a layer of ice was formed.

Twenty days later, on 26 February, the first group of oysters w
returned to the laboratory and placed in water of the same temperatu
as that outdoors. Then the temperature was slowly raised to abo
17°C for 2 days. Following this recovery period fifteen oysters we
placed in spawning dishes and our usual method of inducing spawni
was applied. Eight of fifteen oysters responded, of which five we
females and three were males. Spawnings were light to medium wi
a total of 27 million eggs released. These eggs were cultured by o
usual method, but only a comparatively small number of larv
developed to straight-hinge stage.

On 6 March another group of the oysters was brought into t
laboratory from the outdoor tanks and later induced to spawn. Fo
out of eight oysters spawned, three of which were females. The to
number of eggs discharged by these females was 57 800 000. T
majority of the eggs were normal in appearance, although a few we
deformed and some were small.

In one of the containers, in which 375 000 eggs from this spawni

e placed in 5 gal of water, a count of straight-hinge larvae was
de 48 hr later and showed that the culture contained 155 000 normal,
ight-hinge larvae, 11 000 abnormal ones and 2 000 dead individuals.
erefore, approximately 168 000, or about 45% of the eggs placed in
culture developed into larvae. In another culture, where approxi-
tely 750 000 of these eggs were placed in 10 gal of water, the count
de 48 hr later gave 424 000 normal, 46 000 abnormal and 32 000
ad larvae; therefore, approximately 502 000, or 67% of all the eggs
at were originally placed in the culture developed to straight-hinge
age. From then on, however, larval development was poor, showing
gh mortality.

On 19 March, 43 days after the ripe oysters were placed in the icy
ater, another group was brought in and, after being kept for 4 days
running sea water at a temperature ranging between 14° and 17°C,
s induced to spawn. Both males and females spawned. One of the
males released 18 million and another, 27 million eggs. Larvae
tained from eggs of one of the females grew well, increasing approxi-
ately 10 μ in length per day.

This experiment demonstrated the remarkable fact that oysters
tificially ripened in the middle of winter can be transferred abruptly
om warm to freezing water, retained there for over 40 days, and then
turned to warm water and induced to spawn, producing viable eggs
d sperm that eventually develop into normal straight-hinge larvae.
ven though mortality among larvae obtained in this unusual manner
as relatively high and many larvae were abnormal, the experiment
emonstrated, nevertheless, the remarkable power of oysters to retain
eir ripe sex cells under extremely adverse conditions. Results of
istological studies of gonads of oysters involved in these experiments
ill be described later in a special publication.

Regardless of the ability of ovarian eggs of *C. virginica* to withstand
xposure to low temperatures for long periods, recently fertilized eggs,
the polar-body stage of development, do not display the same
lerance. This was demonstrated by an experiment in which eggs,
ithin 1 or 2 hr after fertilization, were placed in a refrigerator main-
ained at a temperature of about 2°C, and kept there for 6, 24 and 48 hr.
amples were then returned to room temperature and further develop-
ent of the eggs subsequently observed. In all samples a few eggs
eveloped into abnormal ciliated blastulas, but practically all of them
ailed to develop further and soon disintegrated.

Healthy shelled larvae of oysters, *C. virginica*, are, nevertheless,
apable of withstanding sharp changes in temperature of the surround-
ng water. In a special series of experiments, designed to verify Nelson's

conclusion of extreme sensitivity of these larvae to temperat changes, beakers of 1-liter capacity containing larvae grown at a te perature of about 22°C and measuring about 200 μ in length w placed in a refrigerator at 2°C and returned to room temperat following 6, 12 and 24 hr of refrigeration. Within a few hours predominating majority of larvae exposed to the low temperature 6 and 12 hr were swimming and feeding normally. However, many the larvae which were refrigerated for 24 hr lost a portion of the vel and eventually died. The mortality in each of the above groups the end of one week after return to room temperature was: cont 4·2%; 6-hr chilling, 6·5%; 12-hr chilling, 4·9%; and 24-hr chilli 44·9%. Thus, even though exposed to a near freezing temperat for a 24-hr period, more than half of the larvae survived and contin to develop.

In still another experiment oyster larvae lived and grew w subjected every 48 hr to a sharp drop in temperature, from 20° to 10 for periods of 15 to 30 min, followed in a few minutes by an equa abrupt return to 20°C. A majority of these larvae subsequen reached metamorphosis. It would seem unlikely, therefore, claimed by Nelson (1921), that ordinary short-term temperat fluctuations of only a few degrees, occurring in natural waters, co be responsible for an appreciable, sometimes total mortality larvae.

It is also certain at this time that bivalve larvae may surv long periods with little or no food. In many of our experiments seve control cultures survived from 2 to 3 weeks with little or no mortali even though they did not receive any food except that which present in the filtered sea water where they were kept. Moreover, our earlier experiments, before such good food forms as naked flag lates became available, many oyster larvae cultures were kept for m than 40 days, although they did not show any growth. As alrea mentioned, in some of these cultures setting began only after 50 da These observations demonstrate that bivalve larvae may toler comparatively long periods of semi-starvation and some may e reach setting size and metamorphose regardless of poor feeding con tions. It is improbable, therefore, that under natural conditions lar populations of such mollusks as oysters will die within 2 or 3 d because of a lack of sufficient quantities of food. It is clear, howev that lack of food will prolong the larval period, thus increasing loss of larvae because of predation and dispersal.

Larvae are also able to tolerate very low oxygen concentrations, least for short periods. For example, on several occasions a number vae were accidentally left overnight in a small pipette of sea water, they were found alive and healthy the following day.

Recent studies of Davis (1958) have clearly demonstrated that eggs d larvae of at least some estuarine species, such as *C. virginica*, can lure sharp changes in salinity. This matter will be discussed more ensively in the section dealing with the general aspects of changes salinity upon development of eggs and larvae.

Studies of effects of turbidity upon eggs and larvae of *C. virginica* avis, unpublished) and those of *M. mercenaria* (Davis, 1960), which ll be discussed later in greater detail, have demonstrated that larvae these two species can endure and even continue to grow in water at is quite turbid. For example, Davis has shown that larvae of *virginica* may survive for at least 14 days in a concentration of 2 g silt per liter of sea water. Such a heavy concentration seldom occurs nature.

Fertilized eggs and larvae of many bivalves can also withstand gorous mechanical disturbances without ill effects. For example, obtain a representative sample of the population from our culture ssels, the water is strongly agitated by means of a plunger to assure a mogeneous distribution of larvae. Such relatively rough treatment, ually performed every day or every second day, does not cause an crease in mortality or decrease the rate of growth of larvae. Observa-ons on the behavior of larvae in nature also support this conclusion cause, as shown by our studies of plankton samples and by observa-ons on intensity of setting of oysters on natural beds, it has been finitely established that strong winds accompanying New England rricanes and churning the water of Long Island Sound steadily for veral days do not noticeably diminish larval populations. This was pecially well demonstrated in August 1955, when a marked increase intensity of setting of oysters occurred immediately after hurricane Connie ". This increase continued for 2 weeks, thus showing that rvae of all ages survived the hurricane. It is also of interest that tting of oyster larvae occurred during the hurricane, thus indicating at strong water turbulence does not easily destroy larvae or seriously terfere with their metamorphosis.

Recent studies have repeatedly demonstrated the sensitivity of valve larvae to traces of certain substances in the water. These servations showed that sea water, in which our larval cultures are own, sometimes contains substances, so far unidentified, which termine whether larvae will grow normally (Loosanoff *et al.*, 1951; avis, 1953). Wilson (1951) found similar differences between natural a water collected from widely separated areas of the ocean. We are

still not certain whether it is the presence of deleterious mater
or absence of growth-promoting substances in sea water that sl
growth or prevents normal development of larvae.

We have observed that some substances which interfere w
normal development of larvae may originate from sources to wh
we have previously paid little attention. Under certain conditi
these substances may be released mechanically from bottom soil. T
was noticed during a winter when a deep channel was dredged
Milford Harbor, from which our laboratory obtains its water. Dur
that period the water acquired certain properties which stron
interfered with normal development of eggs and larvae. These s
stances were apparently in solution or in fine colloidal suspens
because they were still present in the water after it was filter
Neither aeration nor ageing appreciably improved the quality of
water.

Sensitivity of eggs and larvae to different substances dissolved
sea water was further demonstrated by Davis and Chanley (1956b)
a series of experiments which showed that, while low concentrati
of antibiotics may increase rate of growth of larvae, even a sli
excess of them reduces rate of growth. Progressively increasing c
centrations of these substances correspondingly decrease rate of grow
of larvae and eventually cause their mortality. This matter will
discussed in greater detail in the section devoted to larval disea
and their treatment.

Recently, extensive studies on effects of numerous insecticid
weedicides, oils, organic solvents and detergents on mollusks have b
undertaken at Milford Laboratory. While these studies are still
progress, it has already been found (Davis, 1961) that within ea
group of these compounds there are great differences in toxicity
individual chemicals to eggs and larvae of bivalves. For examp
DDT was found to be one of the most toxic of the commonly u
insecticides because even at a concentration of 0·05 parts per mill
it caused almost total mortality of oyster larvae. On the other ha
another common insecticide, Lindane (1, 2, 3, 4, 5, 6 hexachlorocyc
hexane), even at a concentration of 10 ppm, which is essentially
saturated solution in sea water, caused no appreciable mortality
larvae. On the contrary, growth of clam larvae in 5 ppm of Linda
was somewhat faster than that of larvae in control cultures.

Certain concentrations of phenol, chloramphenicol and Dowic
"A", among the antibiotic, bactericide and disinfectant compou
also appreciably improved rate of growth of bivalve larvae. This
attributed to the action of these compounds which inhibits growth

teria toxic to larvae. Other compounds which, in certain concen-
tions, probably improve rate of growth of larvae by partially
ibiting growth of toxic bacteria are acetone and trichlorobenzene
ong the organic solvents, Monuron and Fenuron among the weedi-
es, and Guthion among the insecticides. Davis (1961) appropriately
gested that, in some phases of shellfish culture, a sufficient concen-
tion of such insecticides as Lindane may be maintained to destroy
undesirable crustaceans, while not affecting growth of bivalve
vae or their food organisms.

Our laboratory and field observations have shown that metabolites
eased by some microorganisms, especially dinoflagellates, seriously
ect not only adult bivalves (Loosanoff and Engle, 1947), but also
velopment of their eggs and larvae (Loosanoff *et al.*, 1953). Such
icity of external metabolites and their physiological effects on
uatic organisms have been recognized by many biologists, some of
se studies having been summarized by Lucas (1947, 1961) and
rringa (1952). More recently, Loosanoff (1955) reported that a
avy bloom of dinoflagellates in Milford Harbor caused abortion of
bryos and immature larvae of gravid European oysters, *O. edulis*.
vis and Chanley (1956b) found that a dense bloom of dinoflagellates
used abnormal development of eggs and larvae of the clam, *M. mer-
aria*, and oyster, *C. virginica*. Under these conditions only a few
veloped into shelled veligers. During that summer concentrations
dinoflagellates in some areas of Milford Harbor were as high as
0 000 cells per ml. Placing eggs of clams or oysters in this water,
en after it was passed through a Millipore filter to remove dino-
gellates, resulted in only a slight increase in the percentage of clam
oyster eggs that developed normally.

Although we assume that the effects noted above were due to
ternal metabolites emitted by dinoflagellates, it is possible that they
re caused by removal from sea water, by these cells, of certain
bstances necessary for normal development of clam or oyster eggs
d larvae. Another possibility is that the presence of a certain sub-
ance, favoring rapid growth of dinoflagellates and preventing normal
velopment of larvae, was simultaneously responsible for both
enomena.

F. *Effects of temperature on eggs and larvae*

Certain observations and experiments devoted to studies of effects
sudden and extensive changes in temperature on eggs and larvae
several bivalves have already been described in the preceding section.

Here, we shall briefly discuss the results of observations on effect temperature within a much more limited range.

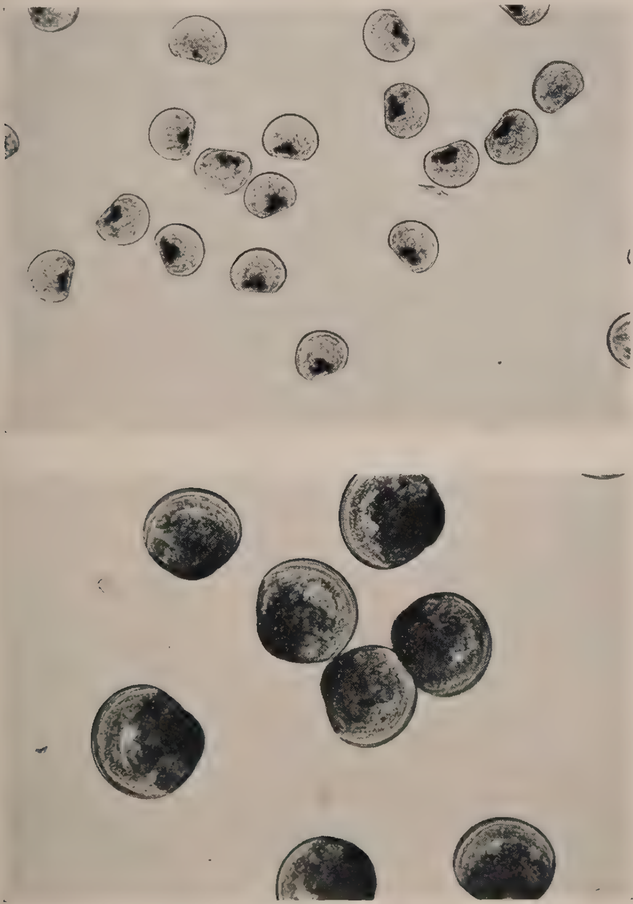
Larvae of most of the species cultured at our laboratory were gr under routine conditions, i.e. at room temperature, which was norm near 20°C. Because of this no extensive information is available a temperature ranges within which larvae of different species survive or their optimal growing temperatures. In a few spec nevertheless, rather extensive observations on effects of tempera on development of their eggs and on growth of the larvae were un taken. Studies of this nature on *M. mercenaria* and *C. virginica* h been the most complete.

M. mercenaria has been grown from egg to metamorphosis at c stant temperatures ranging from 18° to 30°C (Loosanoff *et al.*, 19 If, within 3 hr after fertilization, eggs of these clams were place water of 15°C, virtually none of them developed normally to straig hinge stage. If eggs were kept at room temperature from 6 to 9 after fertilization and then subjected to a temperature of about 1 some developed into straight-hinge larvae. The majority of th larvae, however, were abnormal and many of them soon died, altho some continued to grow at a very slow rate.

If eggs and, later, larvae developing from them were kept at ro temperature for the first 2 days after fertilization, until straig hinge stage was well formed, and then placed in water of 15°C, som the larvae survived for 12 days or even longer. It is possible tha given good food, some of the individuals might eventually re metamorphosis. However, if larvae grown at room temperature for first 2 days of their existence were placed in water of 10°C (Fig. they would not grow.

At the other end of the temperature range, at about 33°C, abnor development and heavy mortality usually occurred if recently fertil eggs were transferred to water of this temperature. However, if e and, later, larvae developing from them were kept at room tempera for the first 48 hr after fertilization and then transferred to wate 33°C, rapid normal development, similar to that observed in cult kept at 30°C followed. Thus, our observations on development eggs and growth of larvae of *M. mercenaria* at temperatures from to 33°C support the view expressed by Pelseneer (1901) that nor early cleavage stages of molluscan eggs are limited to a narro temperature range than can be tolerated by more advanced stage the eggs or larvae.

Larvae of *M. mercenaria*, developing from eggs within the te perature range of 18° to 30°C, grew to metamorphosis, growth be erally more rapid at higher temperatures. At 30°C larvae began to as early as the 7th day after fertilization. Sometimes, the entire ulation grown at this temperature would metamorphose within



IG. 19. Differences in sizes of 12-day-old larvae of *Mercenaria mercenaria* grown at 10°C (*above*) and 30°C (*below*). Average lengths of larvae were 105 and 195 μ, respectively.

to 7 days. When grown at 18°C the first metamorphosing individuals ere noticed 16 days after fertilization, although in some cultures this vent did not occur until after 24 days. Other factors, such as quantity nd quality of food, density of larval population, etc., are no doubt

responsible for these variations. However, by maintaining the cult
at a constant temperature of 24°C and providing the larvae with g
food, such as *Isochrysis galbana*, we consistently bring cultures

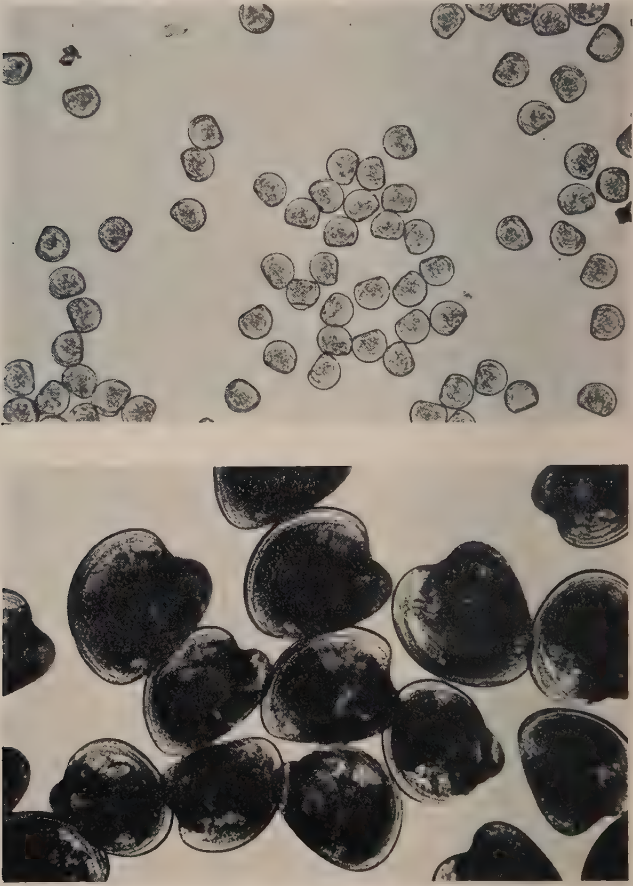


FIG. 20. Differences in sizes of 12-day-old larvae of *Crassostrea virginica* grow
10°C (*above*) and 33 C (*below*). Average lengths of larvae of cold and warm w
groups were 77 and 203 μ, respectively.

M. mercenaria to the beginning of setting 12 days after fertilizati

In experiments designed to determine temperature limits
development of eggs of *C. virginica* it was found that at 17·5°C
many as 97% of the eggs may develop to normal straight-hinge sta

15°C, however, none of the eggs reached this stage although a few d veloped as far as early shelled larvae.

In some experiments 100% of recently fertilized oyster eggs trans- f red directly to 30°C developed into normal straight-hinge larvae, t, at 33°C, only 48% or less reached this stage. The abnormal larvae this group were unable to feed or grow even when returned to a t nperature of 24°C.

Although 2-day-old larvae placed in water at constant tempera- res of 10° and 15°C for 12 days did not grow (Fig. 20), their rate of rtality during this period was comparatively low. The larvae kept 10°C for 12 days could not feed even after being returned to a nperature of 24°C. However, some of the larvae kept at 15°C for e same length of time and then returned to 24°C fed, but their growth s negligible. Larvae kept at 17·5°C took some food, but also showed tle growth. The majority of these larvae, however, began to grow pidly when returned to water of 24°C.

At temperatures of 20°C and higher growth of oyster larvae was, a large extent, dependent upon the food given. When fed *Chlorella* . (580), which is a relatively poor food, the larvae grew less rapidly an they did at the same temperatures when given better foods. evertheless, even when fed *Chlorella* sp. growth of larvae within the nge from 20° to 33°C increased progressively with each increase in mperature.

Recent experiments suggest that one of the ways in which low mperature may affect growth of bivalve larvae is through inactivation certain enzymes. For example, clam larvae kept at 10°C can ingest od organisms but are apparently unable to digest them. This is well own in the upper photograph of Fig. 19. Larvae kept at 15°C can igest and assimilate naked flagellates and grow slowly, but are unable utilize *Chlorella* sp. Those kept at 20°C were able to utilize both the aked flagellates and *Chlorella* sp. Similarly, larvae of *C. virginica* kept t a temperature of 20°C or lower cannot utilize *Chlorella* sp. How- ver, at 25°C these larvae receiving *Chlorella* sp. showed some growth nd at 30°C they were apparently able to utilize *Chlorella* sp. much ore efficiently and, as a result, grew quite rapidly.

Larvae receiving *Dunaliella euchlora*, a moderately good food rganism, showed a sharp increase in growth between 20° and 25°C. owever, within the temperature range from 25° to 33°C the rate of rowth remained virtually the same.

Larvae given a mixture of our best food organisms, *M. lutheri* and . *galbana*, together with *Dicrateria* sp. (BII) and *Chlorella* sp. (580), rew better at the same temperatures than when fed only *Chlorella*

sp. (580) or *Dunaliella euchlora*. In general, through the range fr
20° to 30°C growth increased parallel with the increase in temperatu
At 30° and 33°C, however, the larvae grew virtually the same and me
morphosis at both temperatures began consistently between the 1
and 12th days.

G. *Effects of salinity on eggs and larvae*

Bivalves, even though they belong to the same class of mollus
display extremely wide differences in their salinity requirements a
in ability to withstand sharp or gradual changes in salt content of
water. Therefore, in determining minimum, maximum and opti
salinities for their existence each species, especially those populat
estuarine regions, must be studied individually. For example, del
of rivers, where salinities are relatively high most of the time, may
populated by both *C. virginica* and *M. mercenaria*, while a sh
distance above this line, where the salinity of the water is consid
ably lower than 20 parts per thousand, only oyster beds can be fou
because clams are unable to survive under such brackish conditio
To demonstrate the differences that may exist between two species t
often may be found in the same environment, we shall briefly disc
the differences in salinity requirements of larvae of *C. virginica* a
M. mercenaria.

Loosanoff (1952) found that the lowest salinity at which nor
development of gonads of *C. virginica* of Long Island Sound m
proceed is near 7·5 ppt. Continuing the study of various aspects
variations in salinity on propagation of American oysters, Davis (19
demonstrated that 22·5 ppt was the optimum salinity for developm
of eggs of oysters that had grown in Long Island Sound and h
developed gonads at a salinity of about 27 ppt. Some normal lar
developed, nevertheless, in salinities as low as 15 ppt and as high
35 ppt. At salinities below 22·5 ppt the percentage of eggs that de
loped to straight-hinge larval stage steadily decreased until, at 15 p
only 50 to 60% of the eggs developed normally. At 12·5 ppt practica
none of the eggs developed into normal shelled larvae.

In another experiment Davis used Maryland oysters that had gro
and developed gonads in the upper parts of Chesapeake Bay wh
the salinity, at the time the oysters were collected, was only 8·7 p
These oysters were spawned at Milford Laboratory in salinities
7·5, 10 and 15 ppt. Under these conditions some eggs developed i
normal larvae even at 10 ppt and 7·5 ppt although, in the latt
slightly smaller than normal larvae were common. In general,
optimal salinity for normal development of eggs of these oysters fr

ry brackish water was between 12 and 15 ppt, while a salinity of ·5 ppt was the upper limit.

When oysters that had developed gonads at a salinity of 27 ppt re used as parents, the optimal salinity for growth of their larvae, er they had reached straight-hinge stage, was 17·5 ppt. Good owth was also recorded at a salinity of 15 ppt, but at 12·5 ppt growth s appreciably slower, although some larvae grew to metamorphosis. 10 ppt growth was practically at a standstill and it is doubtful at any larvae could reach setting stage at this salinity. The older e larvae, however, the better they withstood the salinity of 10 ppt. rvae that were reared almost to setting stage at our normal salinity about 27 ppt continued to grow and even metamorphosed when ansferred to a salinity of only 10 ppt.

Davis (1958) also showed that the optimal salinity for development eggs of *M. mercenaria* of Long Island Sound was about 27·5 ppt. o normal larvae developed at salinities of 17·5 ppt or lower. The pper salinity limit for development of clam eggs was 35 ppt, but only n occasional normal larva developed at that concentration of salt.

Straight-hinge clam larvae grew reasonably well at 17·5 ppt and any reached metamorphosis, but at 15 ppt none of them reached at stage, although some lived for 10 or more days and showed a ight increase in size. At 12·5 ppt straight-hinge clam larvae showed o growth and all were dead by the 10th day.

As can be seen from this brief comparison, eggs and larvae of *C. vir-*
inica can normally develop and grow to metamorphosis in a much wer salinity than those of *M. mercenaria*. Undoubtedly, using resent methods of cultivation of larvae, similar studies will soon be erformed on other species of bivalves and prove to be as informative nd useful as those reported in the recent article by Davis and Ansell 1962) on development of eggs and growth of larvae of *O. edulis* in ater of different salinities.

H. *Effects of turbidity on eggs and larvae*

One of the least studied factors of molluscan environments is that of urbidity (Loosanoff and Tommers, 1948; Jørgensen, 1949; Loosanoff, 1962a). A review of the literature in this field (Jørgensen, 1960) hows that even though some work has been performed on adult mollusks, until the recent contributions of Davis (1960, and unpublished), virtually nothing was known of the ability of bivalve eggs to develop or larvae to survive in turbid waters. Davis employed a rotating wheel, to which culture vessels were attached, to maintain turbidity at definite constant levels. The turbidity-creating substances used in his experiments were the same as those employed by Loosa and Tommers (1948) in their studies on behavior of adult oyst They were fine silt collected from tidal flats, kaolin (aluminium silica powdered chalk and Fuller's earth.

Davis showed that silt was considerably more harmful to egg oysters, *C. virginica*, than to those of clams, *M. mercenaria.* example, in concentrations of 0·25 g/l of silt only 73% of oyster e survived, while more than 95% of clam eggs developed to straig hinge stage. Practically all clam eggs developed to straight-hinge st in concentrations of 0·5 g/l of silt, while only 31% of oyster e survived.

In a suspension of kaolin and Fuller's earth, on the other ha clam eggs showed much higher mortality than eggs of oysters. Th in concentrations of 1 g of these substances per liter of sea wa practically all oyster eggs developed to straight-hinge stage, w only 37% and 57% of clam eggs survived.

Strangely enough, of the materials which were tested in th experiments, silt, a natural substance, was more harmful to oys eggs than either kaolin or Fuller's earth. While practically none of eggs exposed to 1 g/l of silt reached straight-hinge stage, some e developed normally even in concentrations as heavy as 4 g/l of ka or Fuller's earth.

As in the case of eggs of these two species, silt was more harmful oyster larvae than to clam larvae. At a concentration of 0·75 g/l silt growth of oyster larvae was markedly decreased while, as a strik contrast, clam larvae grew normally even in 1 g/l of silt. Moreov the majority of the clam larvae survived for 12 days and even show some growth in 3 and 4 g/l although it is doubtful that they co reach metamorphosis under these conditions.

Kaolin and Fuller's earth were considerably more harmful to cl larvae than to oyster larvae. Concentrations of 0·5 g/l of kao caused about 50% mortality of clam larvae in 12 days and, wh practically no clam larvae survived in concentrations of 1 g/l of eith kaolin or Fuller's earth, growth of oyster larvae was not apprecia affected by 1 g/l of kaolin. Davis also found that some oyster larv may live as long as 14 days in concentrations of 2 g/l of silt and to 4 g/l of either kaolin or Fuller's earth. These observations dem strated an unusual ability of larvae of *C. virginica* to withstand high turbid water, a situation often existing in summer at or near mout of rivers where natural oyster beds are found.

In several experiments, where small quantities of turbidit creating materials were added to water containing straight-hinge larv oysters or clams, growth of these organisms was stimulated, often coming considerably more rapid than in control cultures. Possibly, is was a result of adsorption, by particles of such materials, of toxic ıbstances formed in larval cultures. It is also possible that some of ıese materials that were added to the water contained a positive rowth factor, as do certain soil solutions.

In summarizing the observations on the effect of turbidity on vster and clam larvae, it may be concluded that larvae, as well as dults, are affected by turbidity-creating substances, although larvae em to display a considerable tolerance towards some of these aterials. Moreover, larvae of different species react differently, one pecies may be more tolerant or less resistant to the same material nder the same conditions. It is significant, nevertheless, that in some ıstances comparatively light concentrations of common silt may trongly interfere with normal development of eggs of some bivalves.

I. *Effects of foods on growth of larvae*

In any laboratory, where large numbers of adult and juvenile ollusks are kept, these animals, because of limited space, are often rowded, receiving insufficient quantities of water and, therefore, ood. To improve these conditions we add large quantities of artificially-grown plankton to the water flowing through troughs and trays.

Because of the scope of our work several hundred gallons per day f relatively rich phytoplankton are often needed. Obviously, it is mpractical to grow such large quantities of plankton in glass flasks ısing common laboratory techniques. Fortunately, by merely adding omplete commercial fertilizers to sea water, rapid growth of phytolankton can be initiated and later maintained in heavy concentrations. ur experiments have shown that fertilizers designated by formulas -3-5 and 6-3-6, both used by Connecticut tobacco growers, gave the est results, although lawn fertilizer, 10-6-4, was also good (Loosanoff nd Engle, 1942). Using these fertilizers, mass cultures of rich, mixed plankton have been continuously grown at our laboratory since 1938. A wooden, 2000-gal oval tank is used for this purpose, although on several occasions the cultures have been grown in outdoor, concrete, 10000-gal tanks. The sea water used in these tanks was passed through a sand filter.

To supply the laboratory in winter with a sufficient quantity of plankton we designed a special enclosure, resembling a greenhouse, in which a plankton-containing tank is installed (Fig. 21). By providing artificial light, when needed, and maintaining the temperature of the

enclosure at the desired level, the laboratory is now supplied w
rich, mixed phytoplankton on a year-round basis.

A common difficulty experienced in growing phytoplankton
open tanks of several-thousand-liter capacity, as is done at Milford
invasion of these cultures by zooplankton organisms. In our m
cultures the most common offenders are crustaceans, especially co
pods. These forms multiply so rapidly in rich phytoplankton that th
soon consume most of the plant cells, rendering the culture useless

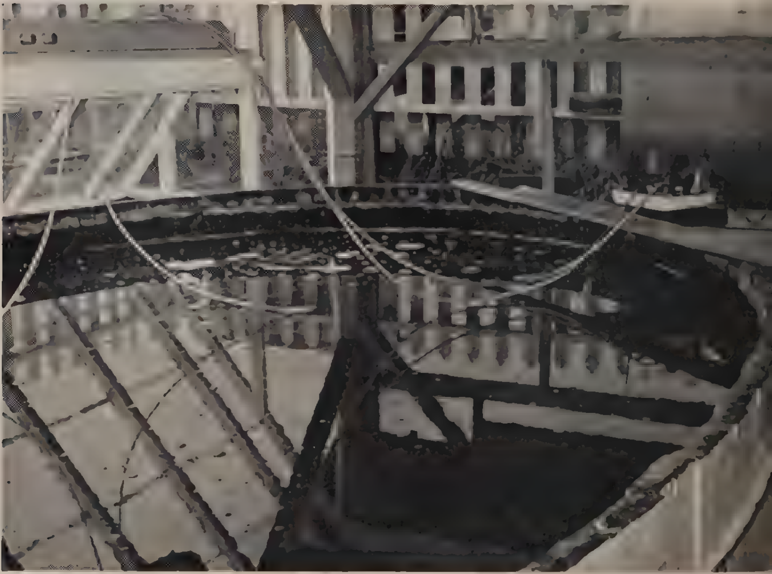
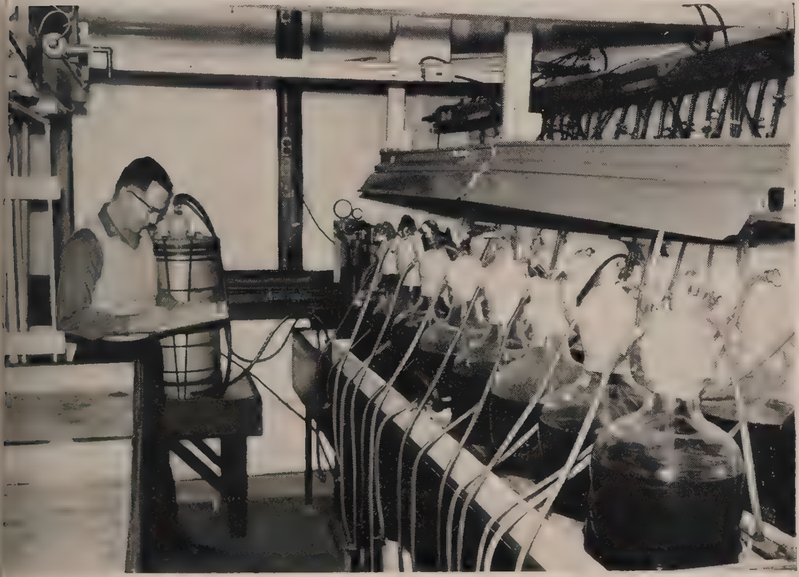


FIG. 21. Mass culture of mixed phytoplankton grown in large wooden tank of ab
2 000-gal capacity under semi-outdoor conditions. Description in text.

In the past, several methods were tried to prevent such contami
tion of open-air algal cultures, but they usually were unsuccess
because some crustacean eggs were always left behind and eventua
hatched, reinfesting the cultures. Recently, we developed an extrem
simple and safe method to control these infestations by merely add
to our cultures, when necessary, small quantities of insectici
(Loosanoff *et al.*, 1957). Several of these substances have been tr
and found successful in concentrations as low as 0·1 ppm. At prese
we use a commercial preparation known as TEPP, which contains 4
of tetraethyl pyrophosphate. The advantages of using TEPP

at it hydrolyzes within 24 to 48 hr and it has no permanent effect . algae; therefore, it does not impair the usefulness of the culture as food for mollusks.

The mass culture grown in our tank is not a single species but a ixture, the composition of which varies from day to day or even hour hour. This culture usually contains various species of *Chlorella*-like ganisms, but because *Chlorella* is not one of the best foods for larval ınd juvenile mollusks, it has become necessary to grow on a large scale uch forms as have been recently found to assure good growth and low nortality of larvae. Moreover, because it was found by our European olleague (Walne, 1956, 1958) and at our laboratory (Davis, 1953; Davis and Guillard, 1958) that bacteria in sea water, especially in lgal cultures, may seriously affect lamellibranch larvae, sometimes ot only slowing their growth but causing complete, or almost complete nortalities, we made special efforts to develop a method by means of vhich virtually bacteria-free algal cultures can be grown. To achieve his an apparatus was devised and placed in operation at our laboratory



IG. 22. Battery of specially-fitted, 5-gal Pyrex carboys serving as growth chambers for mass culture of photosynthetic microorganisms. Description in text.

approximately 3 years ago and has since consistently given satisfact
results (Davis and Ukeles, 1961).

The culture apparatus consists of sixteen 5-gal Pyrex carboys
growth chambers (Fig. 22). Vigorous agitation, by bubbling a mixt
of air and CO_2 through the cultures, keeps the contents of the chamb
thoroughly mixed. This prevents stratification and helps to exp
all cells to equal periods of strong illumination. The carboys
immersed to a depth of 3 or 4 in in a water bath kept at a desi
temperature, usually 19° ± 1°C. About 3 liter of the algal culture fr
each growth chamber are harvested each day, yielding about 1·5
of packed wet cells. The present system, thus, produces daily appro
mately 50 liter of algal suspension, averaging 0·5 ml of packed cells
liter.

A volume of sea water, nutrient salts and antibiotics, equal to
volume of culture drawn off, is added daily to each growth chamb
The sea water used is first passed through Orlon filters, previou
described, to remove larger particles. Nutrient salts are then ad
and this solution is forced through a ceramic bacteriological fi
(Selas No. FP-128-03, maximum pore size 0·6 μ) into the grow
chambers. Recently, we have been adding to the sea water and nutri
salts, prior to final filtration, 0·002% Acronize (approximately 1
chlorotetracycline) to reduce bacterial growth on the ceramic filt
This concentration of Acronize does not interfere with algal grow
and helps prolong the life of the cultures.

Although *Chlorella* sp. and a number of other algae will grow o
media made from 5-3-5 or 6-3-6 fertilizers, a more elaborate media
needed for our bacteria-free cultures. Since the requirements of ea
of the more than eighty species of marine algae maintained at
laboratory have not been determined, we use the following as " univ
sal " media, although it is recognized that the necessity for the vari
ingredients has not been ascertained. Two stock solutions of nutri
salts are prepared and 1 ml of each is used per liter of sea water.

Solution A

Dissolve in 1 liter of distilled water

NaH_2PO_4	20·0 g
Thiamine HCl	0·2 g
Biotin	0·001 g
B_{12}	0·001 g
Pyradoxine HCl	0·1 g
Calcium pantothenate	0·2 g

Solution B

Dissolve in 1 liter of distilled water

$NaNO_3$	150·0 g
*NH_4Cl	50·0 g
Ferric sequestrine	10·0 g

* Media for *Isochrysis galbana* should omit the NH_4Cl.

Experiments conducted at our laboratory have shown that some ecies of bacteria are harmless, others are strongly pathogenic, and ill others produce toxic metabolites. It is quite possible, therefore, r some bacterized cultures of algae to be good larval foods, while e same algae, with a different bacterial population, may be acutely xic. Consequently, for critical evaluation of any phytoplankton rganism as a food for larvae it is necessary to use a bacteria-free ulture of it. Furthermore, in using mass cultures of algae, where there always danger of bacterial contamination, it should always be ascertained that the cultures have not become contaminated with toxic r pathogenic bacteria.

As already mentioned, certain species of algae also produce metaolites that are toxic to bivalve larvae, while other species produce ittle or none (Fig. 23). Some of the algae produce so much toxic naterial that they are useless as foods because their toxins kill arvae even when concentration of algal cells is too light to satisfy arval demand for food. Others, such as *Chlorella* (580), produce ome toxic products but are still usable foods, provided that their oncentrations are not too high.

Recently, Davis (1953) and Davis and Guillard (1958) concluded hat presence and thickness of cell walls and degree of toxicity of netabolites are important factors in determining usability of photoynthetic microorganisms as larval food. They showed that the naked lagellates, *I. galbana* and *M. lutheri*, were of approximately equal alue as food for larvae of the American oyster and induced more apid growth than any of the other species tested. Davis also believes hat *I. galbana* and *M. lutheri* produce little, if any, toxic external metabolites which unfavorably affect larvae. This is supported by his bservations that the optimal concentrations of the two forms for ither clam or oyster larvae were at least double the optimal concentrations of *Chlorella* sp. (Lewin's isolate).

The food value of microorganisms also depends, in part, upon how completely they meet the food requirements of larvae. It was found, for example, that a mixture of *I. galbana*, *M. lutheri*, *Platymonas* sp. and *Dunaliella euchlora* induced more rapid growth of both clam

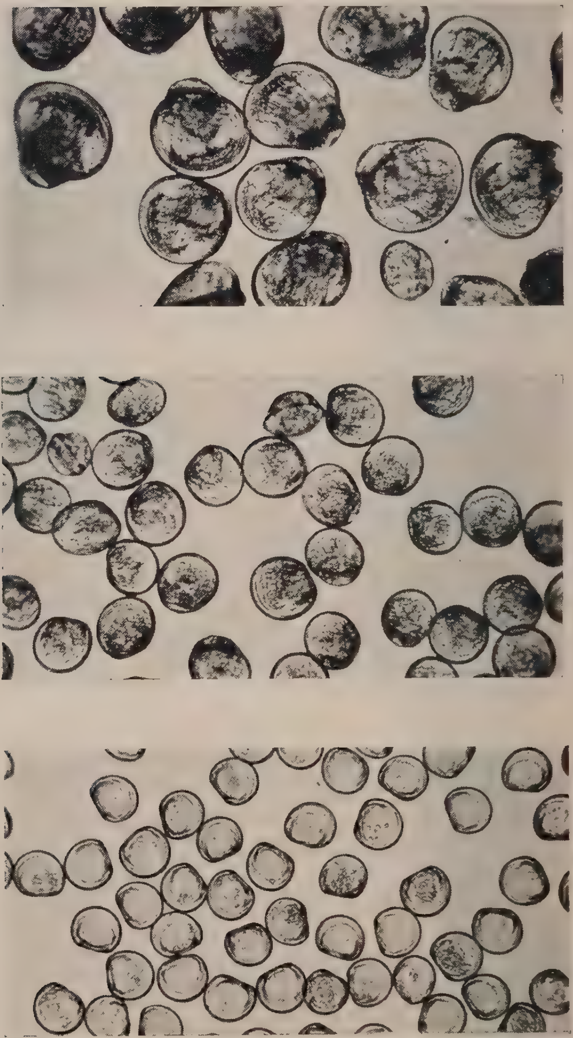


FIG. 23. Twelve-day-old larvae of *Crassostrea virginica* given different algae as f
Group fed *M. lutheri* (*upper photograph*) averaged 169 μ in length, while the mi
group, serving as control and receiving no supplementary food, averaged 96 μ.
lower group, containing only dead larvae, was given *Stichococcus* sp. isolated f
Great South Bay, Long Island, New York, which produces toxic metabolites.

a l oyster larvae than did equal quantities of any of these foods arately.

D. euchlora and *Dunaliella* sp., both naked flagellates, as are *galbana* and *M. lutheri*, also induced better growth of oyster larvae ring the first 6 days of their development than did any of the forms ving cell walls. Thus, Davis concluded that, with the exception of *ymnesium parvum*, which is toxic, even the poorest of the naked gellates is a better food for young larvae of *C. virginica* than any of organisms with cell walls. This conclusion supports the earlier e of Cole (1939) and Bruce *et al.* (1940), that nanoplankton may fer in their value as food for larvae of *O. edulis*. Davis found, never-less, that *Chlorella* (580), *Platymonas* sp., *Chlorococcum* sp., and *aeodactylum tricornutum*, all forms having cell walls, were utilized larvae of *C. virginica*, but growth, particularly of younger individuals, s slow and might have occurred because of presence in the water of her food materials.

Observations on behavior of larvae of approximately twenty fferent species of bivalves grown at our laboratory have shown that, general, as far as their qualitative food requirements are concerned, ey can be roughly divided into two or, perhaps, three groups. The st group, well-represented by larvae of oysters of the genus *Crass-trea*, is able to utilize, during early straight-hinge stages, only a few the many food forms (Davis, 1953; Davis and Guillard, 1958). The cond group includes larvae of such species as *Mercenaria mercenaria* d *Mytilus edulis*, which seem to be able to utilize most of the micro-ganisms, provided that they are small enough to be ingested. The ird, an intermediate group, also can be tentatively recognized. This oup includes such larvae as those of larviparous oysters of the genus *strea*, which are much less restricted in their qualitative food require-ents than larvae of the genus *Crassostrea*, yet they are unable to ow quite as well on some of the foods as larvae of *M. mercenaria*.

The food requirements of the two marginal groups were clearly own in our experiments where larvae of the oyster, *C. virginica*, and am, *M. mercenaria*, were placed simultaneously and kept together the same laboratory culture vessels or in large outdoor tanks. All ltures were given the same food, which consisted of mixed phyto-lankton in which small, green algae, such as *Chlorella*, normally pre-ominated. Under these conditions larvae of *M. mercenaria* grew rapidly nd metamorphosed approximately in 12 days, while larvae of *C. vir-nica*, after attaining straight-hinge stage, showed virtually no growth nd eventually died. The results of these early experiments were onfirmed by Davis (1953), who showed that while young larvae of

C. virginica are unable to utilize forms having cell walls, such *Chlorella*, older larvae of the same species become able to do so af they reach a larger size of approximately 110 μ.

In general, these studies have demonstrated several import points. One of them is that larvae of *M. mercenaria* can live and gr to metamorphosis on a very restricted diet, consisting of a sin species of algae, such as *Chlorella*, and that unlike larvae of *C. virgin* they can utilize these algae during all stages of development. conclusions, therefore, disagree with those of Cole (1936) who maintai that bivalve larvae, in general, do not possess the enzymes needed digestion of cellulose, of which the cell walls of algae, such as *Chlore* are made.

As our techniques improved and we were able to evaluate the f value of different forms of phytoplankton, we found that larvae *M. mercenaria* can be grown not only on a pure culture of *Chlore* reaching metamorphosis in some cases in 12 days, but that t can also be grown to metamorphosis on pure cultures of any one of following three flagellates: *Chlamydomonas* sp., *Chromulina pleiades* *I. galbana* (Davis and Loosanoff, 1953).

Our studies have also shown that organic detritus, at least of types tested, cannot be utilized by larvae of clams, *M. mercena* (Loosanoff *et al.*, 1951), or oysters (Davis, 1953).

Larvae of *M. mercenaria* seem to be capable of both mechani or quantitative, and chemical, or qualitative, selectivity in feedi They are able to regulate the amount of food ingested and thus surv in heavy concentrations of food cells, often containing less food their stomachs than larvae kept in lighter food concentratio Apparently, clam larvae are not merely mechanical feeders, but poss a mechanism by means of which they can control the food intake rejecting algal cells, when necessary. However, if kept in heavy c centrations of algae for a long time, the larvae lose this regulat ability, become choked with food cells and, eventually, die.

We also observed that larvae can select certain food organis from a mixture of several forms of phytoplankton. For example, wh given a mixture of *Porphyridium* sp. and *Chlamydomonas* sp. lar of *M. mercenaria* ingested the much larger cells of *Chlamydomon* while rejecting the cells of the smaller *Porphyridium* (Loosanoff *et* 1953).

An important problem faced in connection with cultivation bivalves was to ascertain the effects of different concentrations food organisms upon larval survival and rate of growth. The fi series of experiments was conducted with larvae of *M. mercenaria* ncentrations of approximately seven larvae per ml, but fed different antities of food, consisting principally of small *Chlorella* measuring ly about 3 μ in diameter. These cells were fed to larvae in concen- t tions ranging from 6 500 to 1 million cells per ml of water in culture ssels. Simultaneously, another series of larval cultures was fed a ialgal strain of another *Chlorella*, the cells of which were about 8 μ i diameter (Loosanoff *et al.*, 1953).

Results showed that optimal concentrations of food cells clearly pended upon their size. When large *Chlorella* was given, the optimal ncentration of this form for best survival and growth of larvae of . *mercenaria* was approximately 50 000 cells per ml, while approxi- ately 400 000 cells per ml of the smaller *Chlorella* were needed to hieve the same results. This suggests that the food value of 400 000 all *Chlorella* cells closely approached that of 50 000 cells of the rger form, both concentrations being near optimum. If the cells are nsidered as perfect spheres, the volume of 400 000 cells, 3 μ in ameter, is approximately equal to the volume of 50 000 cells, 8 μ in ameter.

A concentration of approximately 750 000 cells per ml of small *lorella* was already above the optimum because, when given so much od, the larvae grew more slowly than when given only 400 000 cells r ml of small *Chlorella*.

Larvae of *M. mercenaria* and many other bivalves can be killed if ncentrations of food cells, such as *Chlorella*, become too heavy. gain, these concentrations depend upon the size and kind of cells. or example, approximately 90% of clam larvae were killed within a w days and those that survived grew very slowly or not at all when ven approximately 300 000 cells of large *Chlorella* per ml of water. hen the concentration was increased to 500 000 or more cells per ml, ll clam larvae were killed within 24 hr. However, when given the uch smaller form of *Chlorella*, which measured only about 3 μ, the rvae grew comparatively well in concentrations as high as 750 000 ells per ml.

It is of interest that larvae that managed to survive in heavily verfed cultures usually displayed certain anatomical abnormalities hich, probably, made the larvae unable to ingest food. Perhaps these bnormalities were responsible for survival of these larvae under the onditions where normal individuals were killed.

We realize that, in studying the food requirements of bivalve rvae, the quantity of algal cells in the surrounding water constitutes nly one factor needed to determine the adequacy of a food because his value may be subject to considerable variations according to the

age of the algal cultures, their density, chemical composition, bacte
flora and, of course, the media in which they are grown. These d
culties have been eliminated, to some extent, in our more recent exp
ments where production of food cells has been standardized (Da
and Ukeles, 1961).

As has previously been shown for adult bivalves (Loosanoff a
Engle, 1947), their larvae can be killed either by a heavy concentrat
of algal cells alone, by the filtrate of algal cultures or by a combinat
of the two (Loosanoff *et al.*, 1953). In other words, dense concentrati
of certain food organisms, such as *Chlorella*, affect larvae of *M. m*
cenaria, as well as those of several other species, both mechanica
by interference of food cells with larval swimming and feeding mec
nisms, and chemically, by producing external metabolites which
toxic to larvae. As an illustration, the larvae grew comparatively v
when control cultures received approximately 100 000 cells per ml
large *Chlorella*, even though this concentration was somewhat ab
the optimum for this strain of algae. However, cultures of lar
receiving cells of *Chlorella*, that had been removed from the cult
medium by Millipore filters and later resuspended in sea water at
rate of 1 million cells per ml, were rapidly killed. Similarly, lar
receiving the filtrate only from a certain volume of algal cult
originally containing one million cells of *Chlorella* per ml also quic
died. These studies further showed that a filtrate containing hea
concentrations of metabolites of *Chlorella* cells may be even m
detrimental to larvae than heavy concentrations of the resuspen
cells themselves. As has already been mentioned, the ecolog
effects of external metabolites have long been recognized by aqua
biologists (Lucas, 1947).

Recently, Davis and Guillard (1958) conducted extensive exp
ments to determine the relative value, as larval food, of representati
of ten different genera of microorganisms. *I. galbana* and *M. lut*
were the best foods and were approximately of equal value. In so
experiments, nevertheless, *Chlorococcum* sp. was the best food
larvae of *M. mercenaria*. Clam larvae were also able to utilize seve
species of *Chlorella*, *Dunaliella euchlora*, *Dunaliella* sp., *Platymonas*
Chlamydomonas sp. and *Phaeodactylum tricornutum*. However, t
could not utilize one species of *Stichococcus* or *Prymnesium parvu*

Experiments also demonstrated that, as in the case of larvae
C. virginica, a mixture of *I. galbana*, *M. lutheri*, *Platymonas* sp. a
D. euchlora promoted somewhat more rapid growth of clam lar
than did equal quantities of any of these foods separately.

Some of the algae tested at Milford Laboratory are given below w species listed in their approximately descending order of value as ds for larvae of *M. mercenaria* and *C. virginica*. Several other cies tested are not listed here because they were either poor foods were toxic.

M. mercenaria

A. Good Foods:
- *Monochrysis lutheri*
- *Isochrysis galbana*
- *Dicrateria* sp. (B II)
- *Chlorococcum* sp.
- *Platymonas* sp. (1)

B. Medium Foods:
- *Carteria* sp.
- *Chlamydomonas* sp.
- *Cyclotella* sp. (O-3A)
- *Chlorella* sp. (580)
- *Stichococcus* sp. (O-18)
- *Phaeodactylum tricornutum*
- *Skeletonema costatum*
- *Chlamydomonas* sp. (D)
- *Rhodomonas* sp.
- *Dunaliella* sp.
- *Olisthodiscus* sp.
- *Dunaliella euchlora*

C. virginica

A. Good Foods:
- *Monochrysis lutheri*
- *Isochrysis galbana*
- *Chromulina pleiades**
- *Dicrateria inornata**
- *Pyramimonas grossi**
- *Hemiselmis refescens**

B. Medium Foods:
- *Dunaliella euchlora*
- *Platymonas* sp. (1)
- *Cyclotella* sp. (O-3A)
- *Dunaliella* sp.
- *Chlorococcum* sp.
- *Chlorella* sp. (UHMC)
- *Phaeodactylum tricornutum*
- *Cryptomonas* sp.

* Not tested on clam larvae.

The most recent contribution to our knowledge of food require- ents of the European flat oyster, *O. edulis*, was made by Walne 1956) who also reviewed efforts in this field by earlier investigators. alne conducted over 200 tests using many species of algae. Although e states that many of his experiments were failures, often for no pparent reason, his results showed that the Chrysophyceae, especially *sochrysis galbana* and *Chromulina pleiades*, gave good results, notithstanding that *P. parvum* was toxic to larvae. Members of the hlorococcales, which have a thick cell wall, were found to be poor od for the larvae of *O. edulis*. Of the Chlorophyceae, only *Pyrami- onas grossi* was a good food.

In our experiments we found that larvae of *O. edulis* can be grown n a species of *Chlorella*, even though it has a thick cell wall. In this espect our results disagree with those of Walne and some of the arlier investigators. We agree, however, that naked flagellates,

especially *I. galbana* and *M. lutheri*, are the best foods for larva
this oyster.

Imai *et al.* (1953) mentioned in several articles the successful
of the colorless naked flagellate, *Monas* sp., as a food for oyster lar
Through the kindness of Dr. Imai we received a sample of a cultur
this organism and grew it on a large scale. However, we have co
tently been unable to raise larvae on a diet of this flagellate alone.
our controlled experiments larvae of *M. mercenaria* and *C. virgi*
grew and survived better in unfed controls than when given 4 000
of *Monas* sp. per ml of water in culture vessels. Use of the s
flagellate by oyster biologists of the State of Washington (Lind
personal communication), who also obtained these flagellates f
Dr. Imai, always resulted in failure. Our conclusion that colo
flagellates are not a good food for bivalve larvae is also supporte
recent observations of Walne (1956), who could not raise larva
O. edulis by using another colorless flagellate, *Bodo* sp.

Growing of algal food for larval or juvenile mollusks, even if t
cultures do not need to be kept unialgal and bacteria-free, presen
number of difficulties and, naturally, an easier method of produ
food for bivalves, including adults, is desirable. Our experience, in
late 'thirties, in attempting to increase the glycogen content of a
oysters by feeding them pulverized dried algae, such as diffe
species of *Ulva* and *Laminaria*, led us to try the same approac
feeding larvae with dried algae. In the initial experiments dried
pulverized *Ulva*, which we preserved and kept in a glass jar for
20 years, was used. Surprisingly enough, many cultures of larva
M. mercenaria, given this food, grew to metamorphosis. Howe
several problems were encountered in connection with this meth
First, it was found difficult to grind these algae into particles s
enough to be ingested by larvae. Secondly, the material qui
settled on the bottom, thus becoming unavailable to swimming lar
Finally, because of rapid decomposition of unconsumed algae,
larval cultures became fouled and the bacterial flora in them qui
increased.

Fortunately, we have been able to overcome these difficul
Through the courtesy of Dr. Hiroshi Tamiya of The Tokugawa Insti
for Biological Research in Tokyo, Japan, and Dr. Hiroshi Nakan
of the Japanese Nutrition Association, we received samples of d
Scenedesmus sp. and *Chlorella* sp. Because the average size of
individual cells of both of these algae is small, they can be ea
ingested by larvae. By feeding proper quantities of dried, gro
Scenedesmus in larval cultures, which are continuously agitated

ungers or horizontal-action paddles (Fig. 5), and by controlling e bacterial flora in the cultures by the addition of Sulmet, our ssociate, H. Hidu, to whom these studies were suggested, has been

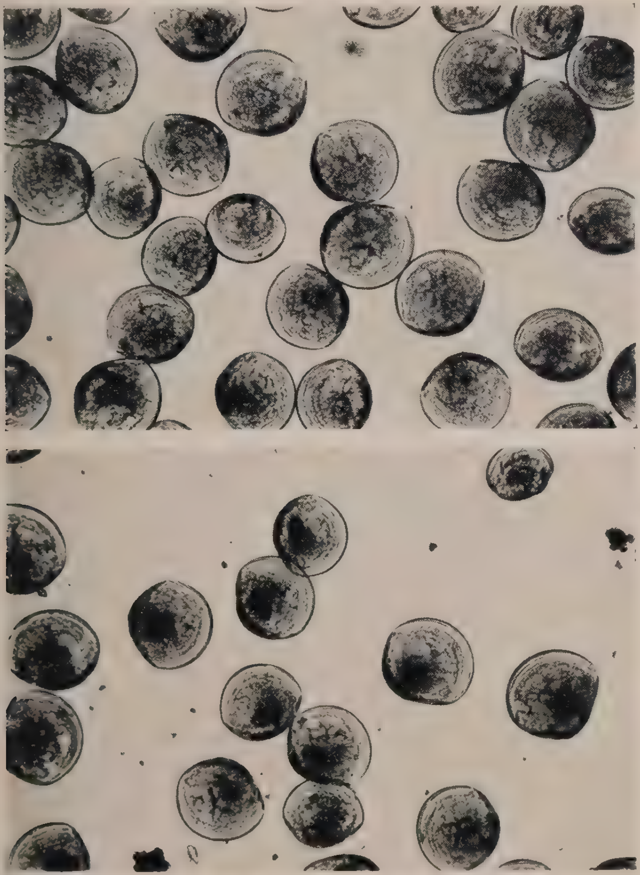


Fig. 24. Twelve-day-old larvae of *Mercenaria mercenaria*. Larvae shown in upper photomicrograph were fed freeze-dried cells of *Isochrysis galbana*, while those in the lower picture were given the same quantities of live cells of the same algae. Largest larvae are about 215 μ long.

able to grow larvae of *M. mercenaria* almost as effectively as when they are fed our best live food organisms, such as naked flagellates. In some experiments clam larvae fed freeze-dried *I. galbana* grew as rapidly as larvae in the control cultures given the same quantities of live cells of the same form (Fig. 24).

When fed *Scenedesmus* clam larvae grew best in concentrations
0·02 ml packed food per liter of water per day. However, dosages
low as 0·005 ml packed food per liter gave just as good results in feed
larvae during their first 4 days of existence (Hidu, personal commu
cation). Agitated cultures treated with Sulmet gave 50 to 10
better growth of larvae than identical unagitated cultures. The type
motion and size of agitating devices appeared to be of little significa
to larval growth and survival. Mortality in all agitated cultures
negligible. In some situations, nevertheless, agitation may not
desired.

Experiments on growing larvae of American oysters on dr
Scenedesmus have been unsuccessful thus far. We are, howev
continuing experiments in this field using, at present in a dried sta
such organisms as *I. galbana* and *M. lutheri* which, when alive,
readily utilized by larvae of *C. virginica*. Results of these and rela
studies will be reported in the near future by Mr. Hidu. It should
realized, nevertheless, that this sphere of research is now only in
initial phase and, therefore, it is too early to form general conclusio
We hope, however, that it will be extremely productive.

In discussing larval foods we would like to emphasize that co
of the larvae themselves depends, to a large extent, upon color
food consumed. By feeding larvae differently colored food organis
we were able, especially during early straight-hinge stages, to cha
their color within a few hours.

Although the color of the shell proper was not always affected,
soft parts of the body quickly changed their coloration which, of cou
reflected on the color of the larvae as a whole. It may also be ad
that according to our observations even the color of shells of recen
set oysters growing in running water is darker than that of oyst
of the same age that are kept in filtered sea water and fed na
flagellates. However, if these pale young oysters are transferred
natural water containing color-carrying phytoplankton, they quic
develop a much darker color. It seems logical to expect that in natu
where combinations of forms constituting phytoplankton cha
frequently, correspondingly frequent and rapid changes in the gene
color of larvae may also occur. We disagree, therefore, with work
who maintain that color is a dependable criterion for identification
bivalve larvae.

J. *Effects of crowding*

An important problem that faced us in early attempts to r
molluscan larvae was to determine maximum concentrations at wh

ey could survive and optimal concentrations for their growth. We xpected these concentrations to depend upon species and quantity nd quality of food, but soon found that such hardy varieties as *I. mercenaria* could be grown in concentrations of 50 to 100 larvae er ml of water. If these cultures were properly attended and fed, ne majority of the larvae survived and, despite their slow rate of rowth, they could, nevertheless, be reared to metamorphosis.

Although these were much heavier concentrations than those dvocated by other investigators, who usually emphasize the danger f overcrowding, we sometimes reared larvae to metamorphosis even nder more crowded conditions. However, since these observations vere of a general nature, special quantitative experiments were ndertaken (Loosanoff *et al.*, 1955). In these experiments larvae of *M. mercenaria* were grown in concentrations of about six, thirteen, wenty-six and fifty-two individuals per ml. Each culture received he same quantity of food, namely, 100 000 cells of a small strain of *Chlorella* per ml of water in the rearing vessels.

Larvae in all cultures showed good survival and grew to metamorphosis, although the mean rate of growth in the different cultures had an inverse relationship to population density. For example, on the 10th day the mean length of larvae in the series of cultures containing six, thirteen, twenty-six and fifty-two individuals per ml was 162, 156, 151 and 144 μ, respectively. Experiments showed that, as reported earlier (Loosanoff *et al.*, 1951), overcrowding clam larvae may not be as dangerous as formerly believed but, nevertheless, rate of growth in overcrowded cultures is slower and time of metamorphosis is correspondingly delayed.

Slower growth in the more crowded cultures may be attributed, in part, to more frequent collisions between the larvae and, in part, to the deleterious effect of greater concentrations of excretory products of larvae. Finally, the fact that there was less food per larva in the more heavily populated cultures was suspected as the most probable cause of slower growth. If this were true, rate of growth of larvae in densely populated cultures should be brought up to normal by a proportional increase in amount of food supplied. Accordingly, a new series of experiments was conducted in which number of cells of *Chlorella* was increased in proportion to increase in larval population. This was achieved by adding daily to the culture vessels containing six, thirteen, twenty-six and fifty-two larvae per ml of water, approximately 100 000, 200 000, 400 000 and 800 000 cells of *Chlorella* per ml.

After 10 days larvae in the least crowded culture averaged 162 μ in length, while larvae in the culture containing thirteen larvae per ml averaged only 148 μ. The two other cultures, containing twenty and fifty-two larvae and given 400 000 and 800 000 *Chlorella* c per ml, died within a few days. This and similar experiments show therefore, that crowding of larvae beyond certain limits cannot alw be remedied by a proportional increase in quantity of food. It also demonstrated that lethal concentrations of food organisms, was the case when 400 000 and 800 000 cells of *Chlorella* per ml w given, cannot always be reduced to a safe level by the large num of larvae that presumably would rapidly consume these cells.

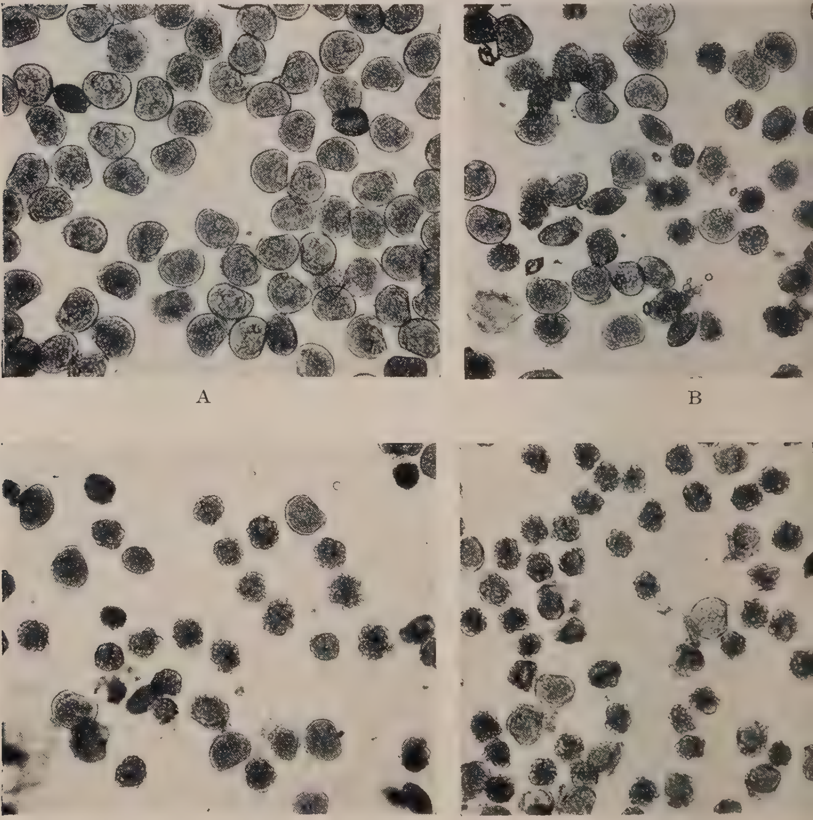

A
B
C
D

FIG. 25. Forty-eight-hour larvae of *Mercenaria mercenaria* developing from cultured at different densities. A, 250 eggs per milliliter of water; B, 500 eggs ml; C, 1000 eggs per ml; and D, 3000 eggs per ml.

Still another experiment showed that eggs and larvae of *M. mercen-ia* can develop under even much more crowded conditions than we ve indicated thus far. In this experiment cultures were begun by acing in rearing vessels 250, 500, 750, 1000 and 3000 eggs per ml of ater. The cultures were incubated at a temperature of about 24°C nd examined at the end of 48 hr. The majority of eggs reared at a ensity of 250 per ml developed into normal straight-hinge larvae ig. 25), while in cultures that were begun with 3000 eggs per ml, ost of the eggs failed to develop past morula stage and those few hat managed to develop to shelled stage were abnormal. In inter-ediate concentrations of 500, 750 and 1000 larvae per ml some eggs anaged to develop into normal straight-hinge larvae but their num-bers decreased proportionally with each increase in the initial concen-ration of eggs.

Experiments on effects of crowding on growth of larvae of the merican oyster, *C. virginica*, were described by Davis (1953). He sed 640, 2 785, 18 518 and 32 918 48-hr-old larvae per liter and gave ll of these cultures the same quantity of food, namely, 50 000 cells f *Chlorella* per ml of water. At the end of 14 days larvae from all ultures were examined and measured. Results showed that there was an inverse relationship between concentrations and rates of growth of larvae. Thus, observations on larvae of *C. virginica* were in agree-ment with similar observations on clam larvae.

On the basis of our results we can conclude that the danger from overcrowding larvae in well-maintained cultures may not be as acute as believed. Nevertheless, crowding is undesirable because it decreases rate of growth of larvae and, obviously, overcrowded larvae are more susceptible to diseases than are larvae in less densely populated cultures.

K. *Metamorphosis*

In such forms as oysters the end of the free-swimming and crawling periods is clearly terminated by attachment of larvae to some clean, hard surface. However, in most of the other bivalves, whose larval development has been studied at our laboratory, the precise or, often, even approximate moment of metamorphosis is difficult to determine because metamorphosis in such forms as *M. mercenaria*, as we have already indicated (Loosanoff *et al.*, 1951), is a gradual process. It is preceded by a stage in which advanced larvae have both a functional velum and a foot, and alternately swim about and crawl on the bottom. This stage, which has been appropriately termed " pediveliger " by Carriker (1956), may last, under certain conditions, for several hours or, perhaps, even days. This opinion is indirectly supported by suggestion of Thorson (1946), Wilson (1958) and other investiga that pediveligers of many bivalves are able to postpone metamorph if conditions of environment are unfavorable for completion of important stage.

Literature contains few references to anatomical changes acc panying metamorphosis of bivalves. This is understandable beca until recently, few forms were successfully and repeatedly gr to this stage. Prytherch's (1934) description of metamorphosi *C. virginica*, Cole's (1938) in *O. edulis* and, especially, Quayle's (1 in *Venerupis pullastra* should be mentioned as contributing to knowledge in this field. However, since a description of the m anatomical changes occurring during metamorphosis does not stitute a part of this paper, no references will be made to the de of this phenomenon in larvae of the mollusks studied by us.

As already mentioned, the number of days required for larva the same species to reach metamorphosis depends upon a com combination of ecological factors, of which temperature and quan and quality of food are the most important. Each species, of course, its optimal temperature range for larval development, as well minimum and maximum levels within which development is possi Since all species that we cultured were grown to metamorphosis room temperatures ranging from 18° to 24°C, it is quite certain this part of the temperature range is comparatively favorable development of most bivalves of our waters, as well as some of exotic species with which we worked. However, information as complete temperature range within which development of each these species is possible is still lacking in most instances.

We have obtained such data for some species. For example already mentioned, in the case of *M. mercenaria* it has been ascertai that larvae grown at 18°C began to metamorphose 16 days a fertilization and continued to set as late as the 30th day. Thus, at temperature, the period between beginning and completion of me morphosis of larvae of the same cultures extended for 14 days. A temperature of 24°C the earliest metamorphosing larvae were noti on the 11th day, and the latest, 22 days after fertilization. At considerably higher temperature of 30°C setting of clam larvae be as early as the 7th day after fertilization and was normally comple within 5 to 7 days, or by the 14th day, although in some of the m erratic cultures the last setting larvae were observed on the 16th after fertilization (Loosanoff *et al.*, 1951).

Similar observations on larvae of *C. virginica* showed that, a mperature of 30°C setting usually began on the 10th or 12th day it, again, it extended for several days, as was the case with clam rvae. At lower temperatures the beginning of setting was delayed nd its duration prolonged. For example, in one culture kept at a mperature of 24°C the larvae metamorphosed continuously for 7 days.

The number of days needed for larvae of the same cultures to reach etting stage is, therefore, not sharply defined even for a culture reared nder standard, well-controlled conditions. In poorly fed, crowded r generally neglected cultures the beginning of setting is usually elayed and the time difference between beginning and end of setting s considerably extended. Sometimes, in cultures kept under poor onditions, towards the end of the experiment large numbers of larvae ere found which were apparently unable to grow beyond a certain tage and eventually died without metamorphosing.

In earlier studies (Loosanoff and Davis, 1950) we were already ware that at the time of metamorphosis the size of larvae varied, ven among those of the same species. At first, the smallest metamorphosing larvae of *M. mercenaria* were thought to be 210 μ long out, later, larvae measuring only about 175 μ but already going hrough this process were seen in the cultures. However, setting occurs most commonly when larvae measure between 200 and 210 μ in length.

The largest larvae do not always metamorphose first. Often, in he same cultures comparatively small individuals only about 180 μ n length will complete metamorphosis, while many larger larvae, exceeding 220 μ in length, still continue to swim.

Since there are several suggestions in the literature that invertebrate arvae reach a larger size before metamorphosis if they develop at low temperatures, we conducted a number of experiments to verify these suggestions (Loosanoff, 1959). This information was desired because if it were true that there was a definite relationship between setting size and temperature at which the larvae were grown, then it should be possible to devise a formula to predict setting size for each temperature.

The studies were conducted with larvae of *M. mercenaria* at temperatures ranging from 18° to 30°C. Within this temperature range there were no significant differences with respect to *mean lengths* of larvae at time of setting. Thus, although larvae grown at lower temperatures required more time before reaching metamorphosis, in all cases the larvae attained approximately the same mean lengths before setting. Furthermore, there was no apparent relationship between *maximum lengths* of larvae at time of setting and water temperat Finally, no relationship was found between shape of larvae (ratic mean lengths to mean widths) at the time of setting and water t perature.

Incidentally, these studies gave us an opportunity to verify opinion expressed by some authors that forms living in warmer wa have just as long a pelagic life as related species living in north waters, and that eggs and larvae of southern species develop n slowly than those of northern species of the same genus if both spe are kept under identical temperature conditions. We conducted tl studies with *M. mercenaria* of Long Island Sound and *M. campechie* imported from the Gulf of Mexico. Both groups were ripened in laboratory under identical conditions and induced to spawn by usual methods. Eggs and larvae of both species were grown a temperature of 21°C in triplicate cultures, and random sample 100 larvae from each culture were taken for length and morta measurements every two days from fertilization to metamorphosi

Results clearly indicated that rates of growth and mortality larvae of the two species were practically identical and that settin larvae of both groups began simultaneously. On the basis of tl observations we may conclude that the belief that eggs and la of southern species, when grown at the same temperatures, dev more slowly than those of the northern species of the same genu not true in all cases.

As has already been mentioned, in some bivalves the beginnin metamorphosis may be delayed because of unfavorable conditi In addition, in at least one case, namely, that of *Anomia simplex*, observed what appeared to be partial or interrupted metamorph (Loosanoff, 1961). While in larvae of this species metamorph commonly occurs at a length of approximately 200 μ, hundred individuals considerably larger than 215 μ were seen in some cult crawling on the bottom by means of a powerful ciliated foot. On these individuals measured 577 × 514 μ.

Partial metamorphosis was characterized by disappearance of velum but retention of a functional foot. Moreover, examinatio these crawlers showed another common characteristic, namely definite narrow band on their shells, which probably indicated edge of prodissoconch, or larval shell, and the beginning of dissoco or post-larval shell. We assume that the band dividing the two port of the shell was formed during an important event in the life of young mollusk, possibly when the velum had entirely disappea or some other equally important anatomical or physiological cha d taken place. This conclusion is supported by measurements of the ner prodissoconch shells surrounded by the band, which were usually proximately 200 μ in length. This is the size at which setting of the ajority of normal larvae of *A. simplex* occurred.

L. *Diseases of larval and juvenile mollusks and their treatment*

Even under the best conditions that can now be maintained in the boratory there have been occasional heavy mortalities of larval and venile mollusks that cannot be accounted for by experimental treatent or errors in technique. Although in most instances this mortality as light, weak or dying larvae could usually be seen harboring heavy opulations of bacteria or protozoans; in some cases the mortality as epizootic, killing nearly all young bivalves within a few days.

The field of diseases and parasites of larval and juvenile mollusks entirely new because studies of this nature were impossible until uccessful methods for rearing larvae were developed. No information as available, therefore, as to whether the bacteria, protozoans, etc., bserved in weak and dying larvae, were the primary cause of their eath or merely secondary invaders and, perhaps, only scavengers. lthough Davis (1953), in attempts to feed oyster larvae on bacteria, ad shown that bacteria retarded growth of larvae and eventually illed them, it was not until 1954 that a fungus, *Sirolpidium zoophhorum* (Fig. 26), was found responsible for some of the epizootic ortalities in our cultures of clam larvae (Davis *et al.*, 1954; Vishniac, 1955). So far, fungus has been found to affect larvae of *M. mercenaria*, *M. campechiensis*, the hybrids of these two species, *Teredo navalis*, *Pecten irradians*, *Tapes semidecussata* and *C. virginica*. However, since t was observed and identified only recently, we have not established whether it can infect larvae of those bivalves which were reared at our laboratory prior to its discovery.

Not all of the forms mentioned above are equally susceptible to fungus. For example, while larvae of *M. mercenaria* and *Teredo navalis* are easily infected, the infection often assuming epizootic proportions, infection of larvae of *C. virginica* is extremely rare. The only case of this type occurred when a large number of fungus-infected clam larvae was introduced into a vessel containing young oyster larvae. Larvae of other forms, such as the bay scallop, *Pecten irradians*, and the Japanese clam, *Tapes semidecussata*, frequently became infected, but the disease seldom reached epidemic proportions.

In *M. mercenaria* and several other species, larvae of all ages, from very early free-swimming stage to those ready to undergo metamorphosis, can be parasitized by fungus. Juvenile clams up to 400 μ in size have also been found severely infected. On many occasions h dreds of thousands of young clams of this size were found dead or dy within a day or two after the first signs of infection were noticed.

Our observations indicate that fungus is introduced into la cultures with untreated sea water or, perhaps, more often with f organisms, such as phytoplankton grown in our outdoor tank in wh the media is not sterilized. It may be the same organism that inf and kills small crustaceans, such as copepods, which are someti present in our outdoor cultures of phytoplankton.

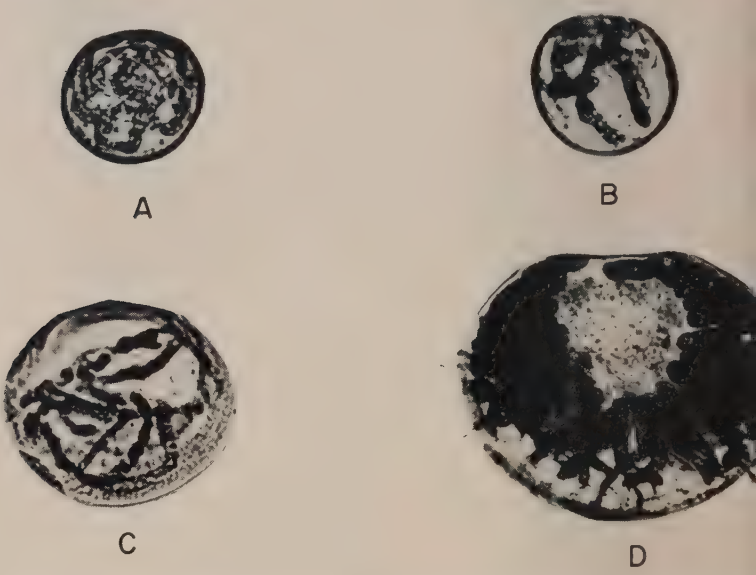


Fig. 26. Larvae infested with fungi. A and B, young larvae of *Crassostrea virg* stained with Neutral Red; C, young larvae of *Mercenaria mercenaria* stained Neutral Red; D, old larvae of *Mercenaria mercenaria* stained with Cotton × 225.

In seeking a method to control fungus infections in our lar cultures we studied the effects of many fungicides, including mos those used in fish hatcheries. So far, not a single promising compo has been found. As a rule, the chemicals unfavorably affected larvae at concentrations lower than those at which the fungus affected. However, precautionary measures, consisting largely maintaining a general cleanliness of all utensils coming in contact larvae and in using germicidal ultraviolet rays to treat all wa gave promising results. Plankton food, if it comes from impure m ltures, should also pass over the ultraviolet tubes. This measure, in dition to controlling the fungus, also protects larval cultures against vasion by undesirable forms, such as small crustaceans, larvae of fferent worms, rotifers and protozoa, which compete with bivalve rvae for space and food. In some instances raising the water tem- rature to approximately 32·5°C for several hours may kill fungus ithout causing serious injury to young mollusks.

Ultraviolet treatment of sea water for purification of shellfish has en described by several workers in Japan, and by Wood (1961) in ngland. Waugh (1958) and Walne (1958) also used ultraviolet-treated a water for rearing larvae of *O. edulis*. To prevent fungus diseases of oung clams we began using ultraviolet light in 1954 to treat sea water nd soon found that this treatment was helpful in preventing mortality f juvenile clams kept in trays of running water. In the summer of 955 it was found that larval cultures receiving ultraviolet-treated a water, but untreated phytoplankton from the outdoor tank, eveloped fungus, while cultures receiving the same phytoplankton nd sea water, both of which were treated, did not become infected.

Because of these observations and because it had long been recog- ized at our laboratory that many mortalities in larval cultures were aused by bacteria (Loosanoff, 1954; Davis and Chanley, 1956b), it ecame our standard practice, since the summer of 1955, to use filtered nd ultraviolet-treated sea water in all larval cultures and in standing vater trays containing recently set clams.

Walne (1958) also reported that bacteria may seriously affect arvae and Guillard (1959) demonstrated, while working at our labora- ory, that certain bacteria produce toxins that can retard growth of arvae or kill them. Guillard isolated two virulent clones, one of which ppeared to be a species of *Vibrio*, and the other, of *Pseudomonas*. His xperiments showed that larvae of *M. mercenaria*, when exposed to irulent bacteria and treated simultaneously with antibiotics, such as enicillin and streptomycin sulfate, remained as healthy as the control ultures. High temperature, near 30°C, favors growth of bacteria, thus mphasizing some of the disadvantages of growing larvae at comparatively high temperatures. Bacterial metabolites, when present in high concentrations, may stop larval growth entirely. Guillard also noticed that bacterial contamination of algal food cultures sometimes caused a sharp decrease in growth of larvae without, however, causing immediate extensive mortality.

More recently our associates, Chanley and Tubiash, again isolated bacteria from moribund and dead clam larvae. When these pathogens were seeded into cultures of clam or oyster larvae they caused almost

complete mortality of larvae within 12 hr (Fig. 27). Later, these stra
were reisolated from moribund larvae to satisfy Koch's postulat
These studies are still in progress and it appears that the recent i
lation deals with different clones from those observed by Guillard

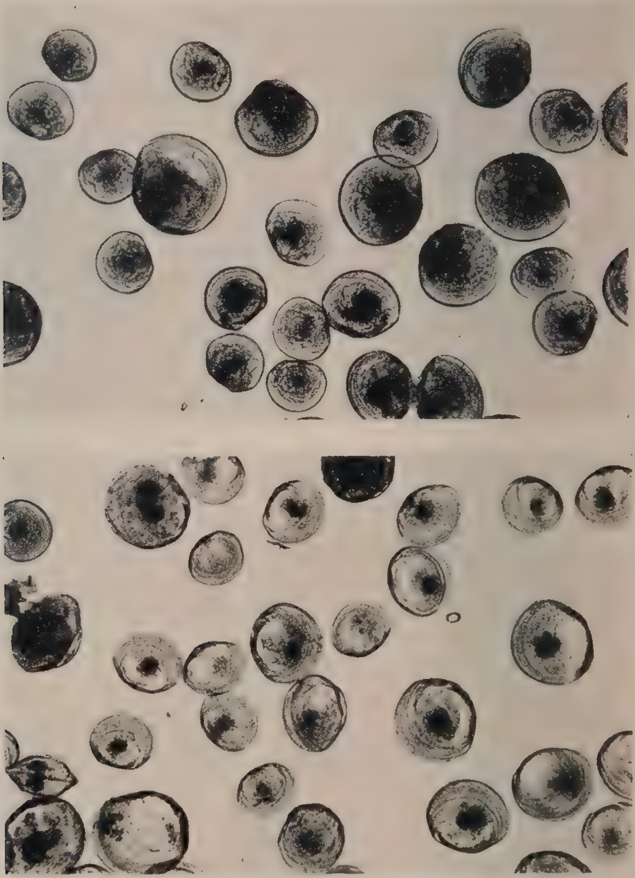


FIG. 27. Effect of pathogenic bacteria upon larvae of *Mercenaria mercenaria*. Hea
larvae (*above*); larvae from the same culture 12 hr after inoculation (*below*). La
larvae in this photomicrograph are approximately 150 μ long.

Following recognition of the pathogenicity of fungi and bact
we began testing a number of antibiotics and fungicides, in addit
to using physical measures for prevention of diseases, to determ
their effects on survival and growth of larvae (Davis and Chan

6b). It was found that at low concentrations streptomycin, aureo- cin, Combistrep (a mixture of dihydrostreptomycin and strepto- cin sulfate), and Sulmet (sulfamerazine) increased the rate of growth clam larvae but that, as concentrations were increased beyond ertain limits, the rate of growth was retarded and, at still higher concentrations, the larvae were killed.

The most rapid growth of clam larvae occurred in cultures contain- g about 100 ppm of streptomycin or Combistrep, in about 33 ppm Sulmet and in only 3 ppm of aureomycin. The increase in rate of owth of clam larvae in cultures receiving 3 ppm of aureomycin was t as great as in cultures receiving optimum concentrations of other tibiotics, such as streptomycin, Combistrep or Sulmet. The com- ercial preparations of terramycin, sulfathiazole and sulfanilamide re somewhat toxic in minimum concentrations tested and retarded owth of larvae. Combistrep, even at 100 ppm, which is the optimal ncentration for clam larvae, retarded the rate of growth of oyster rvae.

In some tests streptomycin did not reduce larval mortalities but, r certain pathogens a closely related compound, Combistrep, in con- ntrations ranging from 125 to 200 ppm has proved to be quite fective. Acronize (chlorotetracycline HCl) at 10 ppm and chloro- ycetin at 20 ppm have also been found effective for certain pathogens. urthermore, cultures of clam or oyster larvae, routinely receiving 3 ppm of Sulmet with each change of water, consistently showed ither better survival or more rapid growth, or sometimes both, than arvae in cultures receiving no treatment. Although at this concen- ration Sulmet did not appreciably decrease the number of bacteria, n some instances, where larvae in untreated cultures grew poorly, reatment with Sulmet improved their growth remarkably. In these ases, we believe, poor growth of larvae in untreated cultures was aused by toxins produced by bacteria introduced with food cultures. The much better growth of Sulmet-treated larvae, therefore, must ave been due either to a reduction in number of the bacteria that roduced the toxins or to a removal of the toxin from solution by forming a nontoxic complex with the Sulmet.

We find that, in addition to antibiotics, several substances, including such unrelated compounds as phenol, the insecticides Lindane and Guthion, the weedicide Endothal and such presumably inert substances as silt and kaolin, when present in proper concentrations cause a similar improvement in rate of growth of larvae. We suspect that it is the result of removal of toxins from the water in larval cultures. This is, probably, accomplished either by adsorption on particles, such as

silt and kaolin, or by formation of nontoxic complexes with la
organic molecules of antibiotics and pesticides.

We have also found that routine use of certain chemicals
improve survival of larvae and aid in control of many fouling
competing organisms. One of these extremely useful compound
polyvinylpyrrolidone-iodine, known commercially as PVP-Iodi
Recently set clams will remain open and feed for at least 24 hr
concentrations of 100 ppm of this compound, and they can toler
250 ppm of it for 24 hr, although in this concentration they will rem
closed most of the time. We have also found that as little as 50 p
of this compound can protect juvenile clams from certain pathoge
bacteria and that, in cultures free from organic debris, 250 ppm
PVP-Iodine will kill bacteria, free-swimming and attached cilia
some annelid worms and even crustaceans.

Good survival and growth of juvenile clams can also be hel
by the following treatment: The cultures are treated overnight,
approximately 18 hr, with 100 ppm of PVP-Iodine. During this ti
the flow of water is stopped; the young bivalves, therefore, remain
standing water. Upon completion of this part of the treatment
water is turned on for a period of 48 hr, and then the second 18
of treatment with 250 ppm of PVP-Iodine in standing water is appli

Pentachlorophenol at 1 ppm, formalin at 40 ppm, and dichloroph
at 10 ppm are other compounds that have been found useful in c
trolling certain bryozoans, ciliates and ascidians that sometimes in
trays or other containers of hatchery-reared juvenile mollusks.

M. *Selective breeding and hybridization*

Development of reliable standard methods for cultivation of lar
opened fields of studies of heredity of bivalves and their select
breeding. Using these methods it is now possible to cross individu
showing specific characteristics and attempt to develop strains,
races, of oysters, clams, mussels, scallops, etc., with such desira
characteristics as rapid growth, high glycogen content in their bod
resistance to certain diseases and, finally, ability to propagate
exist under less favorable conditions. For example, the ability
reproduce at lower temperatures, say, within the range of 13°–16
may extend the oyster beds of such species as *C. virginica* seve
hundred miles northward of their present geographical limits.

Davis (1950) and Imai *et al.* (1950b) were among the first to st
cross-breeding experiments of commercial bivalves. Davis found t
crosses of *C. virginica* ♀ × *C. gigas* ♂ and *C. gigas* ♀ × *C. virginic*
showed a lower proportion of eggs developing to veliger stage than

-hybrids. Moreover, neither group of hybrid larvae could be reared netamorphosis, while under the same conditions non-hybrid larvae . *virginica* and *C. gigas* grew to setting stage. In both hybrid sses fertilization and early larval development apparently progressed mally but about 5 days later, after reaching straight-hinge stage, th larvae died.

More recently, Imai and Sakai (1961) presented results of their ensive studies of crossing different strains of Japanese oysters, *gigas*. According to these authors the hybrids displayed a greater ptability to environmental conditions than the inbred strains. ai and Sakai also reported that hybrid oysters can be grown from sses of *C. gigas* and *C. angulata*, while in the case of crossing *C. gigas* h *C. virginica*, *C. echinata* or *C. rivularis*, cross-fertilization might te place but hybrid larvae will not survive.

It has also been demonstrated that two closely related species of hard shell clam, *M. mercenaria*, of Long Island Sound and *M. npechiensis* from the Gulf of Mexico can be successfully crossed oosanoff, 1954). Larvae resulting from these crosses were often own to metamorphosis, perhaps as a result of hybrid vigor, at a ster-than-normal rate.

Many thousands of juvenile clams from these crosses, after they ched sizes ranging from $\frac{1}{8}$- to $\frac{1}{4}$-in, were distributed to a number marine laboratories along our Atlantic and Gulf coasts for observa- ons on their survival, behavior and growth under different conditions. ually, together with the two groups of hybrids, non-hybrid juveniles *M. mercenaria* and *M. campechiensis* of the same age as the hybrids re also included. A number of papers, including those of Haven and ndrews (1957), and Chestnut *et al.* (1957), described the observations survival and growth of these four groups of young clams.

Chanley (1961) using the techniques for rearing larvae from crosses selected clams showing certain peculiarities demonstrated that shell arkings of *M. mercenaria notata* were inherited as a simple Mendelian aracter with incomplete dominance. In another series of experiments crossed two unselected clams and used the faster growing offspring tained from that cross as parents for the next generation. He com- ared growth of progeny of these clams with growth of progeny of two ndomly selected individuals. When grown under the same conditions r 15 months progeny of the fast growing individuals were 60% larger an progeny of the randomly selected individuals.

V. Rearing of Different Species

Since much of the material discussed earlier in this article was based on our observations and experiments on larvae of *C. virgi* and *M. mercenaria*, these species will be considered first. However avoid repetition of the material already discussed, information rearing of larvae of these two bivalves will be presented in the form comparatively brief review.

A. *Crassostrea virginica* (Gmelin)

A discussion of the literature on various aspects of propagatio this species has already been given in the earlier part of this articl

By using different methods these oysters can be conditioned spawning throughout the year and, if necessary, several times annu (Loosanoff and Davis, 1952a). Spawning is induced by raising temperature within the range from 20° to 32°C, depending upon previous temperature régime. Addition of suspensions of sex produ helps to stimulate the spawning. Eggs can be stripped and fertili

Eggs of *C. virginica* vary in size from 45 to 62 μ, but the majo measure between 50 and 55 μ. Costello *et al.* (1957) stated that the of the oyster egg varied between 45 and 54 μ. The size of the egg is influenced by the size of the mother oyster. For example, eggs charged by females 30 to 40 years old and over 9 in long avera 50·4 μ and ranged between 48 and 54 μ in diameter, while the e from much younger and smaller females, approximately 6 years old 4 in long, averaged about 51 μ, the difference being insignificant.

Under favorable conditions 90 to 95% of ripe, properly hand eggs can develop within 24 hr to shelled veliger stage. The smal normal straight-hinge larvae measure approximately 68 × 55 μ. 48 hr, at a temperature of about 22°C, the larvae measure ab 75 × 67 μ. At this stage they already begin to take in particu food.

The length of the larvae, measured parallel with the hinge l continues to be approximately 5 to 10 μ greater than the wi measured from the hinge to the ventral edge of the shell, until the lar reach the size of 85 × 80 μ. At 95 to 100 μ the length and width approximately equal, but after that stage the increase in width is m rapid. When the length reaches 125 to 130 μ the width already exce it by about 10 μ. This 10 μ disparity between the two measureme remains virtually constant until the larvae reach metamorphosis.

The length–width ratio of larvae of *C. virginica* is almost lin except for the section roughly confined to the length between 105 130 μ where it displays a tendency to form a flat curve. It is of inte that the length–width curve of the closely related species, *C. gigas*, Japanese oyster, clearly shows the same tendency.

The majority of larvae of *C. virginica* metamorphoses between 275 d 315 μ in length, but occasionally free-swimming larvae may be 5 μ long. Larvae were grown to metamorphosis at temperatures nging from about 17° to 33°C; at the latter temperature some larvae tamorphosed in about 12 days. Naked flagellates, such as *I. galbana* d *M. lutheri*, are the best foods, whereas some of the green algae th thick cell walls, such as certain *Chlorella* species, are not readily lized by early veligers, especially at comparatively low temperatures.

Stafford (1912), in his paper on recognition of bivalve larvae in nkton collections, offered a description and drawings of larvae of *virginica* of different stages. His description and, especially, the ngth width relationships of the larvae are widely different from ours. r example, Stafford gives the following length–width (depth) asurements, in microns, as typical for oyster larvae: 82·8 × 69·0; 0·4 × 96·6; 124·2 × 110·4; 151·8 × 131·1; 165·6 × 144·9; 207·0 × 3·2; 310·5 × 276·0; and 345·0 × 303·6. A comparison with our data ows that the majority of the above length–width ratios cannot pply to larvae of *C. virginica*. For example, we found that among the 0 of our larvae measuring 110 μ in length the width varied only from 5 to 125 μ. In other words, none of these larvae were only 96·6 μ ide, as indicated by Stafford. His discrepancies in length–width tio are even greater when he gives measurements of larger larvae. inally, his larvae always measure more in length than in width epth) although, as has already been mentioned, when a length of out 125 μ is reached, the width of the larvae begins to exceed the ngth by about 5 to 10 μ and continues to do so until metamorphosis. ullivan's (1948) measurements and photomicrographs of larvae of *virginica* are quite accurate.

The color of larvae varies somewhat with the food, but healthy rvae are usually a golden brown, particularly in the area of the igestive diverticulum. Young larvae are usually pinkish-orange *en asse*, but this color changes to brown and, later, to almost black as he larvae grow larger.

Larvae are highly active and remain in suspension throughout the ee-swimming period. Large larvae, 200 μ or more in length, have a ndency to gather on the surface of the water and may appear as mall " rafts " floating just beneath the surface. A pronounced " eye " pot develops, when larvae are about 270 μ in length, and is present hroughout the remainder of the free-swimming period.

Larvae of *C. virginica* may be affected by fungus, *Sirolpidium oophthorum*, and die, but they are much less susceptible to this isease than larvae of *M. mercenaria* and some other forms.

B. *Mercenaria* (= *Venus*) *mercenaria* (Linné)

Literature pertaining to the natural history and propagation
this species has already been reviewed.

These clams can be conditioned and induced to spawn through
the year. As in the case of oysters, both chemical stimulation, by
addition of suspensions of sex products, and physical methods,
increasing the water temperature, are effective. However, strip
eggs, if not treated with certain chemicals, cannot be fertilized.

Eggs proper of these clams measure between 70 and 73 μ in diame
and differ from eggs of some other lamellibranchs in that they
surrounded by a thick membrane, the diameter of which ranges fr

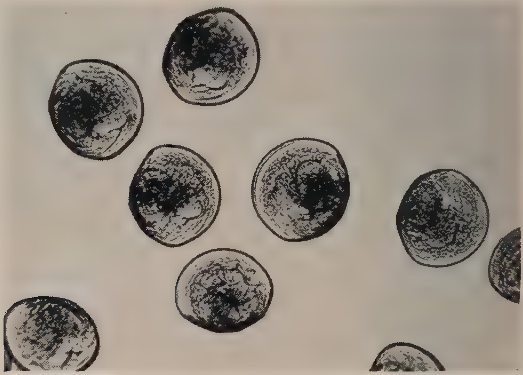


FIG. 28. Larvae of *Mercenaria mercenaria* approaching metamorphosis. Largest i
viduals in this group are about 200 μ in length.

163 to 170 μ. These clams are prolific. A single female was recor
to produce about 24 million eggs in one spawning.

The smallest but apparently normal straight-hinge larva measu
86 × 64 μ, although, usually, the size of early veligers is considera
larger, being approximately 105 × 80 μ and, at a favorable tempe
ture, the majority of normal larvae are from 110 to 115 μ in length

The size at which metamorphosis occurs varies considerab
Larvae ranging from 175 to 240 μ were seen at this stage. Neverthel
metamorphosis occurs most commonly when larvae are betw
200 and 215 μ in length (Fig. 28). Jørgensen (1946) found that me
morphosing veligers of the closely related species *Venus gallina*
from 210 to 225 μ in length. In our case, as indicated above, variati
in the maximum size of prodissoconch of *M. mercenaria* are even grea
than those indicated by Jørgensen. However, in our extensive exp

e larvae of these clams have never approached the size of 320 μ, eported by Sullivan (1948). In a letter to us Miss Sullivan explained t she had confused larvae of *Pitar morrhuana* with those of *M. mer-* *aria* and ascribes the error to the circumstances that newly set spat both species were present in her collection (Loosanoff *et al.*, 1951).

Our observations on maximum size of larvae reached before meta- rphosis also show that it is highly improbable that Stafford (1912) s actually describing larvae of *M. mercenaria* because he stated that igers of this clam grew to a size of 448·5 μ before setting. Further- re, when the shapes of the larvae shown in Stafford's figures are npared with those of larvae grown from eggs at our laboratory, it comes clear that Stafford mistook larvae of some other bivalve for ose of *M. mercenaria*.

Food requirements of larvae of *M. mercenaria* are less restricted an those of some other species, such as *C. virginica*. Clam larvae n be grown to metamorphosis on a diet consisting almost exclusively a unialgal culture of *Chlorella* sp. However, such foods as *I. galbana* d *M. lutheri* promote better growth.

Larvae have been grown at temperatures ranging from 15° to 33°C. the latter temperature setting occurred 6 to 8 days after fertilization.

During early stages the color of the larvae can be significantly anged by differently colored foods. However, as the larvae grow and eir shells become darker, this effect becomes less noticeable. Larvae the same cultures greatly differ in size, especially if they are not roperly attended or are too crowded.

Larvae of *M. mercenaria* are not too selective with regard to the bstratum on which their metamorphosis is completed. They meta- orphose in containers made of a variety of substances, including lass, plastics, earthenware, Plexiglas, concrete and several other aterials. This is contrary to observations on other forms, such as chinoderms (Mortensen, 1938) and polychaetes (Wilson, 1948), where was found that mature larvae postponed metamorphosis until they cated a substratum possessing the necessary physical and chemical haracteristics. In our cultures setting usually began when some rvae were approximately 180 μ in length, regardless of the size of ontainers or material of which they were made.

Setting of clam larvae occurred at approximately the same time, hether they were grown in containers from which all light was xcluded or in transparent glass vessels. Turner and George (1955) ound that clam larvae were rapid swimmers capable of moving upward t the rate of 8 cm/min. However, they showed no detectable reaction o light.

C. *Arca transversa* Say

No description of larval development of *A. transversa* or references to its spawning could be found in the literature.

Our attempts to condition and spawn *A. transversa* in winter with failure or only partial success. Later in the season, about middle of May, some of the "arks" brought in from Long Isl Sound and placed directly in water of 20°C spawned lightly wit 2 or 3 hr. No normal larvae, however, could be grown from these eg Nevertheless, by placing the same "arks" in running sea water 15°C from 3 to 7 days to condition them, spawning was easily indu by raising the water temperature to 27° or 28°C. Both males and fem

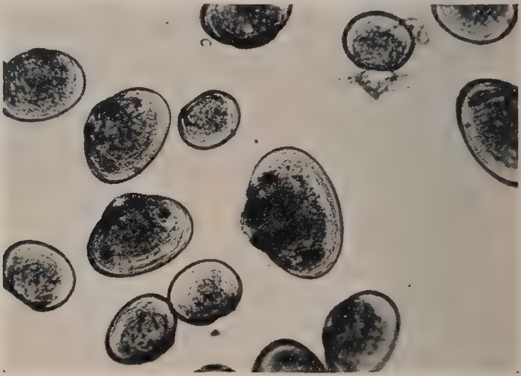


FIG. 29. Larvae of *Arca transversa*. Largest larva, approximately 230 μ in length, be approaching metamorphosis. Note differences in sizes of larvae, all of w are of the same age.

spawned profusely, releasing gametes in streams similar to stream sperm ejected by male American oysters.

The eggs of *A. transversa* are pinkish-orange in color and aver approximately 52 μ in diameter. They are surrounded by a very t almost indistinguishable membrane. The sperm head is roughly angular in shape, with a broad centerpiece. The anterior part of head is "pinched" off in a short, nose-like structure. The head centerpiece of the spermatozoa are between 3 and 4 μ in length, w the tail is from 47 to 55 μ long.

Larvae were grown at room temperature, which was approxima 20°C, and fed mixed phytoplankton composed principally of *Chlor* and closely related forms. Under these conditions the larvae set f 27 to 37 days after fertilization.

Larvae of *A. transversa* are quite distinctive in appearance resem- ng, in general, their adults, particularly as they grow larger. The allest normal straight-hinge larva measured 70 μ long and 55 μ de. Thus, even in the youngest larvae, the difference between length d width is quite considerable. However, when larvae are near tting, the length may exceed the width by about 70 μ (Fig. 29).

The larvae are dark brown in color. As they grow larger, their lor becomes darker and one end of their shells becomes more pointed an the other. Under the microscope larvae appear quite variable outline because their odd shapes cause them to rest in a variety of sitions.

The first indication of an umbo begins to appear soon after the rvae pass 105 μ in length, and at 130 μ it usually is quite conspicuous. hen the larvae reach approximately 140 μ in length the pointed, or ss rounded end of the shell becomes distinctly reddish-brown, while e opposite, more rounded end remains almost brown. This color ifference is quite pronounced in many individuals.

An " eye " spot appears when the larvae are approximately 225 μ ng. In some individuals this spot is not too conspicuous at first, but s the larvae approach metamorphosis it becomes quite prominent. low-growing larvae may develop the " eye " spot at a much smaller ize. For example, in at least one case it was observed in larvae that vere only 205 μ in length.

As is usual in rearing larvae of bivalves, considerable variation vas noticed in setting sizes. The smallest, virtually metamorphosed ndividuals measured only 215 μ in length, while one larva in the ame culture measured about 310 μ and, although it had a large foot, vas observed actively swimming. This may have been a somewhat bnormal individual because a majority of the normal larvae in our cultures set when only 240 to 260 μ long.

Upon reaching metamorphosis recently set clams develop a strong byssus by which they attach to particles of sand, shells or other material.

Unlike larvae of *M. mercenaria* and several other species, which are asily affected by fungi, no epizootics that could be ascribed to these rganisms were observed in our cultures of *A. transversa*.

D. *Modiolus demissus* (Dillwyn)

M. demissus, the common ribbed mussel of our waters, is also eferred to by some authors as *Volsella demissa*, *Volsella plicatula* nd *Modiolus plicatulus*. A review of the literature shows that, except for Sullivan's (1948) article, there are no other references to lar development of this species. Considerable literature, neverthele exists on larvae of *Modiolus modiolus* and closely-related for These references can be found in the papers of Jørgensen (1946) a Rees (1950).

Various methods used to stimulate spawning of other bival proved unsuccessful for ribbed mussels. On two occasions, howev mussels kept in aquaria spawned without artificial stimulation. both cases spawning occurred at night and, when the eggs were fou in the morning they were already undergoing segmentation. Th no measurements of recently discharged eggs were made. Jørgen (1946) states that the diameter of an egg of a closely related spec *Modiolus modiolus*, is about 100 μ.

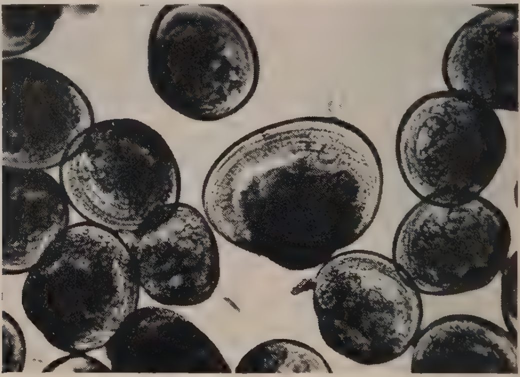


Fig. 30. Larvae of *Modiolus demissus*. Note differences in sizes of larvae that origin from the same group of eggs and were reared in the same vessel. Largest larv center is approximately 300 μ long.

Larvae developing from eggs released during two normal spawni were reared to metamorphosis. At room temperature straight-hi stage was reached in about 24 hr. The majority of the larvae at t time measured from 110 to 115 μ in length and 85 to 90 μ in wid The smallest normal straight-hinge larva was only 105 μ long.

If kept at a temperature of about 22°C and given good food, su as *I. galbana*, many larvae reached a length of 200 μ by the 10th d A few, upon reaching this size, developed a prominent " eye " spot a functional foot. Nevertheless, although completely metamorpho juveniles of a size slightly above 220 μ in length were observed in so cultures, the majority of the larvae did not lose their vela until th hed 275 μ, and a few individuals measuring between 295 and 305 μ in length still retained a functional velum.

While some larvae metamorphosed in about 12 to 14 days after ilization, many others in the same cultures were still free-swimming en the experiment was discontinued after 43 days (Fig. 30). In of these cultures, while there were still free-swimming larvae from to 295 μ long, there were also several thousand completely meta-rphosed juvenile mussels that ranged up to 1 mm in length. Why many of the larvae were still in the free-swimming stage, while others the same cultures had metamorphosed and showed considerable st-larval growth, remained unexplained.

According to Sullivan (1948) the smallest straight-hinge larvae of *demissus* measure approximately 112 × 90 μ. This size quite osely agrees with our measurements. However, the maximum size ven by Sullivan, 205 × 180 μ, is considerably smaller than that served in our cultures, which was about 303 × 260 μ. We also ffer with Sullivan on the color of ribbed mussel larvae because she ates that these larvae are a deep yellow in the early stages, whereas found that throughout their development they are brown.

Jørgensen (1946) discussed larvae of closely-related species. In s references to *Modiolus modiolus* Jørgensen stated that larvae of this ecies have not been identified with certainty in plankton samples ken in Danish waters. He thinks that this is probably due to the ry close resemblance of this species to veligers of *Mytilus edulis*. We sagree with Jørgensen since, in our studies of larvae of these two ecies, we found them to be distinctly different in their length–idth measurements. Furthermore, the difference in their general ppearance, especially during later stages of development, is too great confuse these two groups of veligers.

Rees (1950) stated that in the smallest veligers of *Modiolus* and *Iytilus* the shape is similar, although in the former the narrow end less pointed. Nevertheless, in later stages the shapes of the two enera become more differentiated. Rees also thought that the small pecimens of the two mussels are distinguished more easily by their exture than by their shape. He concluded that Jørgensen's drawing Fig. 167d) is probably of *Modiolus modiolus*, instead of *Mytilus edulis*, s claimed by Jørgensen. However, examination of the photomicrographs of, presumably, *Modiolus modiolus* offered by Rees clearly hows that their shape significantly differs from that of *Modiolus lemissus* grown in our cultures from known parents. This is especially rue of his larvae, approximately 250 μ in length, which have very ittle resemblance to our larvae of the same length.

E. *Mytilus edulis* Linné

A study of the literature on lamellibranch larvae shows t veligers of *M. edulis* have been described more frequently than th of other bivalves. Borisjak (1909) was probably the first to descr these larvae while, more recently, descriptions of presumably the sa veligers were given by Jørgensen (1946), Sullivan (1948), Rees (19 and others.

Mussels with apparently morphologically-ripe gonads are found our waters in early spring, but under laboratory conditions, using method of maturing animals in warm water, ripe mussels can be ma available in January.

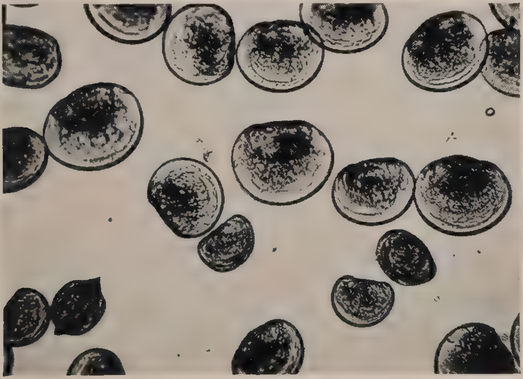
Field (1922) reported that rough handling of mussels, such shaking them in a dish of sea water, will induce spawning within an ho but Costello *et al.* (1957) found this method unsuccessful. In our ca during studies conducted for 3 yr, except for brief periods in Ap and early May, all efforts usually employed to stimulate bivalves spawn failed to work with *M. edulis*. These included sharp increa or decreases in temperature, addition of sex products to the wat keeping mussels in air overnight, placing them in refrigerators various periods, increasing or decreasing salinity of the water, and ev applying light electrical shocks. This was true also of mussels th were conditioned in the laboratory for a considerable time and wh gonads appeared to be morphologically ripe.

Fortunately, it was noticed by two of our associates, first, W. Arc and several years later, J. Uzmann, that some ripe female muss released large numbers of eggs after their adductor muscles were c

These observations suggested a number of experiments on induci spawning in mussels. The first attempt consisted of opening a la number of these mollusks and placing each individual in a separa vessel. The results were rather gratifying because, in the major of cases, the mussels discharged large quantities of normal sex produc The method worked even on mussels that were not laboratory co ditioned. For example, on 26 April 1951, mussels were brought from Milford Harbor, where the water temperature was 8°C. T adductor muscles of twelve females were severed and the muss were placed in water at room temperature. The first two fema spawned within 12 hr; four others deposited masses of eggs with 24 hr, and six remaining females released eggs toward the end of t 48-hr period. This experiment was repeated on several occasio giving virtually the same results.

Eggs released by females with severed muscles were usually di charged in " strings ", as occurs in normal spawning. The major the eggs released appeared normal, but many abnormal larvae were und later (Fig. 31). However, such larvae were also common in ltures grown from eggs discharged in normal spawnings. Mussel gs are orange-yellow in color. They are quite heavy and usually tle quickly on the bottom.

We also noticed that mussels which were dying from some undeter- ned cause often spawned soon after they relaxed their shells, even en their muscles were not cut. This observation suggested that the mulating center, which induces discharge of eggs or sperm, is prob- ly located in the adductor muscles. If these muscles are abnormally laxed or stimulated, spawning follows. This reasoning led to another ries of experiments designed to obtain eggs and sperm from ripe ussels without killing them by cutting their muscles. This modifica- ion of the method would prevent fouling of eggs with blood cells, ecomposition products, large numbers of bacteria, etc., that usually ccompanies collection of eggs from females whose muscles are cut.



IG. 31. Larvae of *Mytilus edulis*. Largest larvae are approximately 170 μ long. Several small, abnormal individuals can be seen in lower right corner.

The new method consisted of inserting a small wooden wedge etween the mussels' shells, thereby stretching the adductor muscle o that the two shells would be forced open about $\frac{1}{8}$- to $\frac{1}{4}$-in. In experi- nents where this principle was used the majority of pegged mussels pawned, while control mussels kept under identical conditions did not. ome began spawning within 2 hr after pegs were inserted and several pawned three times during a single week.

No mortality was noted among pegged mollusks, even when the egs remained between the shells for 10 days. Mussels fed in an apparently normal way, forming true feces and pseudo-feces. Muss that were placed together in large trays with running sea water ev tually attached to each other by their byssus.

Since the second series of experiments has also showed that c charge of spawn in mussels of both sexes can be induced by stretch the posterior adductor muscle, it became more certain that the ne locus causing the discharge is located there. Accordingly, it decided to stimulate this region, by touching or pricking it witl sharp needle, and note whether this type of stimulation would a induce spawning reaction.

In the middle of March two groups of mussels, each composed ten individuals, were placed in running water at a temperature of 19 The first group, the control, contained individuals that were not stin lated. In the second group each individual was gently stimulated pricking the muscle. The first male in the stimulated group spawı in about 2 hr. An hour later the first female spawned and contin to discharge eggs for almost 75 min. The eggs were discharged orange-colored rods, 3 to 4 mm long. These rods were often expel with such force that they travelled 4 to 5 in away from the spawn female.

Seven hours after the stimulation another male spawned, and af 9 hr two more females began to discharge spawn. Within 12 hr ev individual in the stimulated group had spawned, while none in control group had done so. Thus, it was demonstrated that needl the adductor muscle is an effective method of inducing spawn in *M. edulis.*

All mussels that had spawned were later placed in running water to see whether they would survive the stimulation treatme All of them lived for over a month and were then discarded.

Although the previously-described experiment had demonstra that pricking of the adductor muscle stimulated spawning of muss the fact that all ten animals were kept in the same dish left so doubt as to the exact conditions that caused spawning during latter part of the experiment. This doubt existed because toward end both sperm and eggs were present in the water and, therefo might have helped to stimulate the mussels that had not yet spawn To clarify this matter another experiment was designed in which kept each mussel in a separate dish. Again, ten mussels were u in the control group and ten in the group that was stimulated. first male spawned 30 min after stimulation and the first female be to discharge eggs 1 hr after its muscle had been gently touched seve times with the point of a needle. The second female spawned o

3 min after the first one. Both individuals discharged eggs in large nbers for a considerable period. Within 12 hr eight of ten stimulated ssels spawned, while none of the control group discharged any products.

The experiment was repeated four times involving, altogether, mussels. Of the sixty stimulated mussels, fifty-four responded, ile none of the sixty control animals spawned. All mussels of the nulated group remained alive for at least 2 weeks, after which they re discarded. Thus, a very simple method for stimulating ripe mussels spawn has been developed. To make the method even easier we d a small notch at the edge of the shell through which the needle s inserted.

According to Jørgensen (1946) one of the most remarkable peculrities of larvae of *M. edulis* is "its excessive variability both as ards the color of the shell, its shape, and stage of development as npared with larval size, in which respects it is not surpassed by any our other common Lamellibranch veligers" (p. 287).

Our cultures of *M. edulis* were grown during the early period of r studies of molluscan larvae; in other words, before the good food ganisms, *I. galbana* and *M. lutheri*, became available to us. The vae were fed an algal mixture, consisting chiefly of *Chlorella* and her green forms, and grew remarkably well. Strangely enough, it was rtually impossible to injure them by adding to the water large antities of food microorganisms, a situation that often arises in lturing larvae of other species, such as clams and oysters.

The smallest normal straight-hinge larvae measured approximately × 64 μ, and the largest, about 300 × 286 μ. Thus, our measureents are very different from those given by Sullivan (1948), who ated that larvae of *M. edulis* range in size from 155 × 120 μ to proximately 355 × 320 μ. The smallest size given by Sullivan is, erefore, almost 60 μ greater than that of the smallest larvae in our ltures, and the maximum size is considerably larger than that hich we ever recorded among swimming larvae.

Jørgensen also apparently mistook other larvae for advanced ages of *M. edulis* because he speaks of individuals which are 400 μ ng. Werner (1939), whose length and width measurements of larvae f *M. edulis* somewhat resemble ours, still fails to give correct measureents for the smallest straight-hinge stage larvae. In his growth urve for these organisms he gives the size of the smallest larvae as pproximately 112 μ long and 84 μ wide, which is considerably larger han the size of the smallest larvae ordinarily found in our cultures.

The so-called "eye" spot usually begins to appear in larvae when they reach 215 μ in length. This spot is usually located approximat in the center of the larvae and measures from 5 to 7 μ in diame In one individual measuring only 205 μ in length a well-defined " ey spot was found, but this was the only case of an " eye " in suc small larva recorded after examining thousands of individuals. W a length of 230 μ was reached the " eye " spot was present in all lar

The size at which mussel larvae metamorphosed varied by alm 90 μ. The smallest metamorphosed individual, attached by a bys to an oyster shell laid in one of our culture jars, was only 215 × 20 Individuals measuring 225 μ in length, but fully metamorpho and attached by a byssus, were not uncommon. On the other ha some larvae continued to swim until they were almost 300 μ in len Large variations in the size of *M. edulis* larvae at the time of m morphosis were also recorded by Jørgensen (1946). He thinks variable size at metamorphosis is not entirely due to the fact veligers may pass into the bottom stage after attaining a diffe stage of organization, but also because of the varying ratio betw the rate of differentiation of the tissues and rate of growth in diffe individuals.

The factors which govern appearance of the foot and disappeara of the velum in larvae of *M. edulis* are rather baffling. In some insta a well-developed foot was observed in animals as small as 185 length. Such cases, however, were not too common and, usually, appearance of a developing foot occurred as the larvae approac 210 μ in length. Most larvae possessed a well-developed foot by time they reached 230 μ in length, but a functional velum has b observed in larvae as large as 288 μ.

The great differences in the state of organization attained a certain size by larvae of *M. edulis* are also emphasized by Jørgen He gives examples of larvae measuring 250 μ long and nearing m morphosis with well-developed gills and foot and with a velum reduced condition, while in other cases larvae of the same size have only a vestige of a foot but a large velum, thus indicating they are still far from metamorphosing.

The variation in size of larvae at the time of metamorphosis gested a more critical analysis of the data on growth of larvae in same cultures. Fortunately, among our cultures there was one in wh all larvae originated from eggs of the same female and were fertili by sperm of the same male. Regardless of this, 2 days after fertil tion the larvae varied in length from 93 to 120 μ, with an arithm mean of 106 μ. When the culture was 8 days old the length va from 107 to 162 μ, the average being 130 μ. At 14 days some of ae were already metamorphosing and the mean length was 181 μ, some larvae only 128 μ long were still present.

This experiment demonstrated, as we have pointed out on many asions, that it is obviously incorrect to relate the size of larvae to ir age because variations in size, even among larvae that originate m the same parents, are of considerable magnitude. In cultures t are grown at different temperatures and fed different foods these ferences are usually even more striking.

Some workers explain variations in size of larval fish originating m eggs produced by the same female as dependent upon develop- nt of these eggs while still in the ovaries, including proximity of an to large blood vessels which provide the best feeding conditions for ingle egg. Others explain the different rates of survival and growth fin fish larvae as dependent upon quantities of yolk in different eggs. ssibly, the same considerations hold true and, in part, explain riations in rate of growth of bivalve larvae that originate from eggs scharged by the same female in the same spawning.

As is usually the case with larvae of most bivalves, their color varies eatly in accordance with the color of the food microorganisms that ey are able to obtain from water. Larvae of *M. edulis* given heavy ses of purple bacteria rapidly acquired a pinkish color, which was ost pronounced in the area of their digestive organs. If these larvae re later fed green *Chlorella*, their coloration changed to a greenish nt and the livers became dark green. Contrary to Sullivan's (1948) ntentions, no purple tint was observed around the shoulders of the ell, even in advanced larval stages.

F. *Anomia simplex* D'Orbigny

A. simplex is a common bivalve of Long Island Sound, where it ropagates at approximately the same time as *C. virginica*. Because f its more rapid growth immediately after setting, however, this ollusk is a dangerous competitor, since it overgrows and completely vers large numbers of recently set oysters (Loosanoff and Engle, 941).

Descriptions of larvae of several species of *Anomia* are given by tudents working in widely separated parts of the world. Stafford 912) gave a description of *A. aculeata*; Miyazaki (1935) described he larvae of the Japanese species, *A. lischkei*, and Lebour (1938), s well as Jørgensen (1946), described those of *A. squamula*. More ecently, Sullivan (1948) also described larvae of *A. aculeata*, while ees (1950) made a brief reference to three species of *Anomia*. One of these, *A. ephippium*, is a synonym for *A. simplex*. Other ref ences can be found in the above-mentioned articles of Jørgensen a Sullivan.

Large *A. simplex* can be conditioned in December and induced spawn during the first part of January. Some conditioned groups w induced to spawn several times between the middle of January and t beginning of August. To induce spawning presented no probl because, usually, ripe animals began to spawn as soon as the te perature of the water was raised only a few degrees above 20°C. Ev in summer it was not necessary to raise the temperature much abo 25°C. In many instances spawning began without addition of any s products, a circumstance which is unusual in our experiences w spawning of other bivalves.

Artificial fertilization of *A. simplex* eggs is possible. Stripping c be easily accomplished by gently washing the light yellow gon tissue of a female in sea water. The eggs separate easily and ma remain uninjured. Therefore, a high percentage of them ordinar develop into normal larvae.

Compared with eggs of other bivalves, eggs of *A. simplex* are co paratively small, ranging only from 42 to 45 μ in diameter. Beca of their small size the eggs are difficult to handle, as they easily p through the mesh of the smallest screen used for egg retention. Beca eggs and early larvae cannot be strained and, thus, separated from t surrounding water, as is done with larger eggs, in fertilizing eggs *A. simplex* care should be taken not to use too much sperm so as n to pollute later cultures of developing eggs and early larvae.

In our cultures of *A. simplex* the smallest larva with complet formed shells measured approximately 58 × 47 μ. Young larvae a more fragile and transparent than those of *C. virginica* of correspond stages. The " straight-hinge " is actually sloped about 5° so that it somewhat convex. This is difficult to observe under a microscope unl larvae are seen precisely in profile.

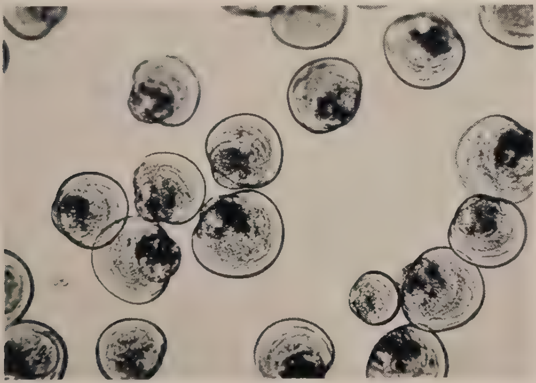
The most common size at which larvae of *A. simplex* metam phosed was at a length of 195 to 210 μ. The largest swimming larv measured approximately 215 × 220 μ. We cannot compare the dim sions and shapes of our larvae with those given by Stafford (19 because his drawings and measurements bear little resemblance to t larvae of *A. simplex* in our cultures.

Sullivan (1948) gave the smallest size of *A. aculeata* as 110 × 10 and the largest as 285 × 280 μ. Jørgensen (1946), in referring to own observations on *A. squamula*, reported that the smallest larv measured 65 to 75 μ in length, and the largest attained a length

0 to 270 μ. Lebour (1938) stated that *A. squamula* may metamorose at a length of only 180 μ, which coincides with our observations *A. simplex*, while Stafford maintained that the veliger of *A. aculeata* i still pelagic at about 350 μ.

The size of larvae of *A. simplex*, when the " eye " spot appears, is ficult to indicate. In a few cases the " eye " was observed in indivials measuring only 136 μ in length although, as a rule, it appeared ien the larvae were near 160 μ. The " eye " seems to be composed from four to six dark bodies grouped together. In many individuals, cluding some that were near setting, no " eye " spot could be stinguished.

Even in early straight-hinge stages there is considerable difference the shape of the two shells. The right shell, or the one that will ventually be the upper, is conspicuously rounded, while the left, or ne one that will become the lower shell is virtually flat. This distinction remains throughout larval development. Jørgensen (1946) eported that in *A. squamula* the umbo of the right shell is not developed. Ve made the same observation on the shell of *A. simplex*.



IG. 32. Larvae of *Anomia simplex*. Largest larvae in photomicrograph are about 160 μ long. Note transparency of larval shells.

An observation made during the rearing of larvae of *A. simplex* oncerned the inconsistency of the appearance on its shell of the indenation known as the byssus notch which, presumably, is diagnostic f larger larvae of this species. Since this was one of the features hich we expected to be rather prominent and to appear in all older arvae, we were somewhat perplexed not to find this notch in many ndividuals. It is true that in some individuals this notch was present in larvae only about 180 μ long, but often it was only a thicke of the shell edge on the side opposite the foot. In our extensive stu of living material and numerous preparations of larvae imbedde balsam, in permanent slides, we were unable to find such " deform larvae as those shown by Sullivan (1948).

Early larval stages of *A. simplex* are very light, almost tr parent in color (Fig. 32). Even larvae nearing metamorphosis rem silvery transparent except, of course, their digestive organs which a rule, take on the color of the food that they contain. In this res our observations are rather different from those of Sullivan (1948), stated that, at first, *Anomia* larvae are pale yellow but, later, bec deep yellow, except for the viscera, which are dark gray.

Since larvae of *A. simplex* may be mistaken for those of oys especially in advanced stages when umbones in both species are q prominent, one way to distinguish the two species is to remember in *A. simplex* the digestive organs are situated much higher, l almost under the umbones.

In the early stages of our work on cultivation of *A. simplex* lar which was conducted in 1950 and 1951, the only food that was r larly available was a mixture of green algae composed largel *Chlorella*. Although the larvae reached metamorphosis when fed food, their growth, as a rule, was slow and mortality heavy. La when cultures of *I. galbana* and *M. lutheri* became available, the la responded well to the new food, growing much faster and show lower mortality. When fed these flagellates at room temperatu many larvae of *A. simplex* began to metamorphose after the 12th although, in the same cultures, some larvae were still swimn 33 days after fertilization.

As already mentioned, one of the most interesting observat made on cultures of *A. simplex* was what appeared to be partial m morphosis, or metamorphosis without attachment to substra (Loosanoff, 1961). Partial metamorphosis was characterized disappearance of the velum, but retention of a functional foot. M over, these partially metamorphosed individuals were unable attach to the substratum, and their shells showed a distinct dema tion line between larval and post-larval portions.

G. *Pecten irradians* Lamarck

The early embryonic development of the bay scallop, *P. irrad* also called *Aequipecten irradians*, has been described by a numb authors, including Fullarton (1890), Drew (1906), Belding (1 utsell (1930) and, more recently, by Costello *et al.* (1957). The later velopment of the larvae, beginning with the formation of the straight-nge stage, however, has never been adequately described because rtually no one succeeded in growing these larvae to metamorphosis. e only exception was Wells (1927), who grew scallop larvae past tting stage, but gave only a superficial description of them, although supplied good photographs showing the different stages of velopment.

Descriptions of eggs and early stages of several European Pectinidae ere offered by Jørgensen (1946). However, as in the case of the merican bay scallop, virtually none of the European workers, except dhner (1914), gave photomicrographs of older veliger stages that may e helpful in identifying the larvae.

The scallops used in our studies were brought, in February, from ong Island, where they are found in a number of bays, harbors and lets. They were placed in running sea water, the temperature of hich was increased within a few days to 20°C. The first spawning as attempted after 23 days of conditioning. The scallops responded adily to a temperature stimulus of about 30°C and spawned profusely.

Scallops usually spawn first as males and, later, as females. During ne spawning, fourteen scallops started spawning as males. However, 0 or 15 min later seven of these fourteen individuals began to discharge ggs, but within a few minutes two of these seven again reverted to pawning as males, releasing large numbers of spermatozoa. On one ccasion the same scallop was observed releasing sperm and eggs multaneously.

Scallop eggs obtained in our experiments measured from 55 to 65 μ diameter, the average size being near 60 μ. Belding (1910) and utsell (1930) gave the size of the scallop egg as 63 μ. Fullarton (1890) eported that the egg diameter of a related European species, *Pecten percularis*, is 68 μ. The scallop egg is surrounded by a thin membrane nd is usually of a pale orange color. Brief remarks on fertilization, leavage and rate of development of the fertilized ovum were given y Costello *et al.* (1957), who based his descriptions on the works of Belding (1910) and Gutsell (1930).

The smallest straight-hinge scallop larvae observed in our cultures ere 80 μ long and 65 μ wide, and the largest swimming individuals, pproximately 200 × 195 μ. Some larvae metamorphosed upon eaching 175 μ in length. Jørgensen (1946) stated that the largest lanktonic stage of the European scallop, *P. opercularis*, is approximately 250 to 260 μ long, while the larvae of another European scallop, *Pecten striatus*, approaching metamorphosis may be only 200 to 210 μ in length, which is in close agreement with the measurement of larv of our species.

Scallop larvae were grown at room temperatures varying betwe 20° and 23°C. They were fed either mixed cultures of plankton co sisting principally of *Chlorella*-like forms or a mixture of flagellate such as *I. galbana* and *M. lutheri.* They grew well on either diet, b cultures fed flagellates grew better. When well fed the growth of larv is comparatively rapid, averaging more than 10 μ per day. In so of our cultures setting began 14 days after fertilization.

Larvae are susceptible to fungus diseases, but fungus does n appear to be as devastating to scallop larvae as it is to larvae *M. mercenaria* or *T. navalis.* Larvae are also highly susceptible bacterial infections.

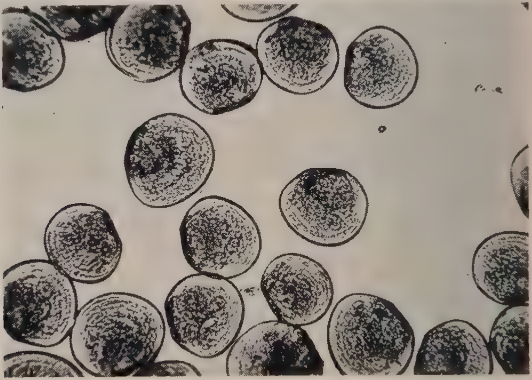


FIG. 33. Larvae of *Pecten irradians.* Largest larvae are about 180 μ long.

Scallop larvae are quite pale and, although the color changes wi the food contained in their digestive system, normal scallop larvae a invariably paler than those of *M. mercenaria.* At all stages they appe slightly asymmetrical, this condition becoming more pronounced larger and older larvae (Fig. 33). In those measuring over 125 μ length a slight notch is evident at the base of the shell, on the le pointed end of the larvae. Although this mark is not too conspicuou it does appear to be characteristic.

Healthy larvae are active and energetic swimmers. Some of the display a small inconspicuous " eye " spot when they reach abo 150 μ in length. Although the " eye " can be seen in most larvae abo 170 μ in length, in larger larvae this spot is virtually invisible, probab because of the thickening of the shell.

H. *Ostrea edulis* Linné

We are interested in this species because its northern races prop- ate at somewhat lower temperatures than the American oyster, *virginica*. Because of this we imported *O. edulis* into the United ates in 1949 in the belief that certain areas along the shoreline of aine and our Pacific coast states were promising for natural propaga- on of these oysters (Loosanoff, 1951, 1955, 1962b). Since then, *edulis* have grown and propagated naturally in New England waters d have become established in Maine. Young oysters reared at ilford, Connecticut and sent to the State of Washington have also rown well there.

Literature on the sexuality and propagation of the European flat yster, *O. edulis*, has been well reviewed by Orton (1937), Korringa 1941), Walne (1956) and Yonge (1960) and, therefore, need not be iscussed here in detail. Using our methods for ripening mollusks out f season we have obtained larvae of *O. edulis* from the end of January o the end of the normal spawning period which, in Milford Harbor, xtends into September. Our attempts to induce spawning of ripe ysters were not always successful. On several occasions, nevertheless, y raising the temperature of the water containing conditioned oysters nd simultaneously adding a suspension of gonad material, spawning as been initiated in both sexes. This was ascertained by finding sperm balls or recently discharged eggs on the bottom of the aquaria. Well-developed eggs ranging in size from 114 to 126 μ were often lost when, during the process of spawning, they were released from the gonad to enter the gill chamber where, normally, they are incubated until larvae are released at swarming.

The manner in which eggs are lost was observed on several occasions during normal spawnings. These eggs were released from the exhalant chamber in a thin stream, almost in "single file". Because only a weak current was carrying them, the eggs settled next to the shells of the mother oysters, eventually forming a small mound. By a gentle moving of the spawning oysters from one area of the aquarium to another and observing the formation of new piles of eggs, it was established that a spawning female may continue a steady discharge of eggs for as long as 4 hr.

Since we could not always induce spawning in conditioned oysters, we depended quite often on unprovoked normal spawnings and subsequent release, or swarming of the larvae. Therefore, when a gravid female was detected, by the presence of a small pile of eggs near its excurrent side, it was placed in a separate aquarium with aerated standing water and kept there until larvae were released. The water was changed daily and the oysters were given sufficient quantiti of food to keep them and the larvae alive.

At room temperatures swarmings took place from 6½ to 10 da after spawning. The size of larvae released by a single female in t same swarming varied considerably. On one occasion samples 100 larvae were collected from swarms released by each of six femal which had been kept in separate aquaria. Larvae released by female (ranged in length from 142 to 199 μ, with a modal size of 186 μ; b female (B), from 164 to 192 μ, with a modal size of 184 μ; by female (C from 164 to 203 μ, with a modal size of 188 μ; by female (D), fro 149 to 203 μ, with a modal size of 187 μ; by female (E), from 164 t 192 μ, with a modal size of 180 μ; and female (F), from 164 to 195 with a modal size of 183 μ. Occasionally, broods of smaller larv measuring 175 × 160 μ were released. The average size of su broods closely resembled those reported by Boury (1928), Voisin (193 and Korringa (1941).

In rare cases the modal sizes of larval broods were unusually larg over 200 μ in length. Because all female oysters incubating larva were kept at the same temperature, it is improbable that the differen in size of the liberated larvae of the different broods was governed b the temperature at which incubation occurred. It seems more reaso able that size of larvae at liberation depends upon how long larva are retained in the mantle cavity. This may be governed by the physi logical condition of the parent oysters or the conditions in the water i which oysters are kept, the larvae being retained longer and, hence, a larger at time of release when these conditions are not at their optimu This is supported by observations on liberation of larvae by two femal that appeared sick. The first was used in an experiment where induce spawning was attempted by quickly raising the temperature to 37° The oyster did not spawn but was apparently injured by this treatme because it gaped for several hours after its return to sea water at roo temperature. It did spawn the next day, however, but the spawnin was not normal because too many eggs were found on the botto of the aquarium near the oyster. The eggs, nevertheless, were fertilize

Ten days later this oyster discharged, simultaneously, a brood larvae and many empty larval shells, indicating that many larvae ha died within the mantle cavity during incubation. There was also considerable number of abnormal larvae with defective vela. Norm larvae, which still were in the majority, measured from 199 to 212 in length, with a modal size of about 208 μ. Regardless of so abnormality observed in the development of this brood, the larv were reared to metamorphosis.

The second release of larger-than-average larvae, measuring between 0 and 210 μ in length, was also observed in an oyster that was pt at high temperature for several hours and was probably injured y this treatment.

Another possibility is that the size upon release may be governed the number of incubating larvae in the mantle cavity, with the rvae growing faster if the number is small.

Swarming or, more correctly, release of larvae by parent oysters as observed on numerous occasions. In general, it resembled dis- arge of eggs by a spawning female of *C. virginica*. The larvae were xpelled in cloud-like masses by a forceful closing motion of the shells. ischarge of larvae by a single female may continue for 3 or even days. Usually, during the 1st day only a few larvae are released. he chief masses of larvae are expelled during the 2nd day and then e number of newly released larvae sharply decreases. Larvae that ad just been released usually contained in their stomach large quanities of algal cells which had been added to the water during their ncubation.

In many of our experiments, including the early one when larvae ere fed phytoplankton composed principally of *Chlorella*, the veligers rew and survived well. At temperatures ranging between 18° and 0°C "eyed" larvae measuring approximately 270 μ, with a prominent igmented spot, began to appear about the 9th or 10th day. Setting sually began on the 15th or 16th day, although in several cases, when ed *I. galbana* and *M. lutheri*, the larvae began to set between the 7th and 8th days.

Setting size of the larvae in our cultures was most commonly between 280 and 300 μ. In this respect our observations agree with those of Cole (1939), who reported that metamorphosing larvae in his experiments measured from 290 to 310 μ. However, we have never observed larvae as large as 350 μ which Cole found in some of his tanks. Imai *et al.* (1953) reported that none of the larvae of *O. edulis* in their cultures reached 300 μ in width, and most of the individuals in Walne's (1956) broods also set before reaching 300 μ.

Throughout the experiments the rate of growth of individual larvae of the same broods showed considerable variations. For example, at the time of setting, when some larvae in a culture already measured 300 μ in length and were undergoing metamorphosis, other larvae still measured only about 175 μ, thus being of approximately the same size as many larvae at the time of swarming.

When recently released larvae were placed in culture jars many of them ascended to the surface and formed large, brown, floating masses, often measuring several square millimeters in area. This congregati tendency apparently did not unfavorably affect larvae. If these mass of larvae were disturbed, the larvae would separate and contin to swim for some time but, later, would again form floating grou Similar floating masses of larvae are frequently observed among old larvae of other species, including *C. virginica*.

I. *Ostrea lurida* Carpenter

The native oyster of our Pacific coast is the Olympia oyste *O. lurida*. It is considerably smaller than its close relative, *O. eduli* or the Atlantic coast oyster, *C. virginica*, seldom exceeding a lengt of 2½ in. Unlike *C. virginica* which, when adult, are of separate sexe the Olympia oyster is hermaphroditic. Its reproduction is also differe from *C. virginica* in that the eggs are not discharged directly in t water but, as in *O. edulis*, they remain within a special brood chamb in the mantle cavity of the mother oyster.

Gonad development and spawning of *O. lurida* can be induced o of season by keeping them in water at about room temperature f several weeks. Spawning can be detected, as in *O. edulis*, either clouding of the water with discharged sperm or by presence on t bottom of a few eggs that were lost during spawning. The eggs measu from 100 to 110 μ in diameter.

According to Coe (1931) Olympia oysters begin to spawn whe the temperature reaches 16°C. Hori (1933) indicated the temperatu as 14°C and Hopkins (1937) thought that spawning occurred soo after the minimum daily water temperature reached 13°C.

In our experiments the incubation period lasted from 7 to 9 da after which swarms of larvae were discharged in the water. Staffo (1914) estimated that in *O. lurida* the period between spawning an swarming was 16½ days. Coe (1931) reported this period as 10 to 1 days, and Hopkins (1937), as about 10 days. The difference in tim is probably due to environmental conditions, especially temperatur under which the different observers conducted their studies.

We were unable to rear successfully recently fertilized eggs that we occasionally lost by females. However, embryos that were lost aft they had reached the ciliated blastula stage were cultured to straigh hinge stage.

In one of our experiments larvae as small as 160 × 149 μ we released at swarming, but these larvae appeared immature as the were too transparent and unable to withdraw the velum complete It was possible, nevertheless, to rear even these small larvae to met morphosis.

The size of normal larvae, at the time of swarming, was about 185 μ, t on several occasions groups of smaller larvae, measuring from 5 to 170 μ were released. Hori (1933) reported that larvae at the me of release are between 175 and 185 μ. Hopkins (1937) gave 180 μ the average. Imai *et al.* (1954), in culturing *O. lurida* in Japanese ters, found that the length of larvae immediately after swarming nged from 174·6 to 189 μ. In general, all these figures closely agree ith ours.

The larvae are quite dark, even when first released, and appear ack when seen *en masse* (Fig. 34). When given good food and kept a temperature of about 24°C growth of these larvae is quite rapid, me of them beginning to set only 7 days after swarming. At 18°C, however, setting does not begin until the 16th day (Davis, 1949). Imai *et al.* (1954) reported that in their best cultures setting began on the 10th or 11th day at temperatures averaging 21·8°C.

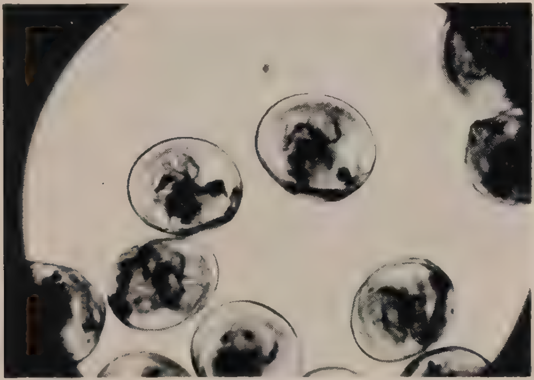


FIG. 34. Larvae of *Ostrea lurida*. Largest larva, near center, is 204 × 185 μ.

Unlike larvae of the genus *Crassostrea*, larvae of *O. lurida* can utilize *Chlorella* from early straight-hinge stage and, in general, appear to be less restricted in types of phytoplankton organisms that they can utilize as food.

Larvae of *O. lurida*, particularly the larger ones, when seen under a microscope appear as thick wedges. Individuals 250 to 300 μ in length may measure as much as 200 μ in thickness if measurements are taken near the hinge, tapering rapidly to the sharp ventral or " bill " side. This makes it difficult to obtain accurate width measurements.

The setting size of larvae grown in our laboratory cultures was approximately 300 μ, which is not significantly different from setting sizes of larvae of *C. virginica* and *C. gigas*. No free-swimming larv measuring more than 312 μ in length were observed. Growth aft metamorphosis was, for a short period, somewhat faster in *O. luri* than in *C. virginica*.

J. *Crassostrea gigas* (Thunberg)

C. gigas, the common commercial species of Japan, was introduc to the waters of the State of Washington in 1902. During the la few decades it has become one of the most important mollusks of o Pacific northwest. Although the industry still depends largely up seed oysters imported from Japan, a natural set of *C. gigas* occu occasionally in such areas as Quilcene, Willapa and Dabob Bays a Hood Canal.

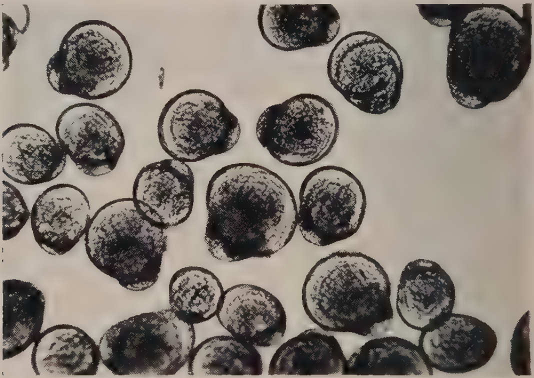


FIG. 35. Larvae of *Crassostrea gigas*. Largest larva, near center, is approximate 175 μ long.

Extensive studies conducted by Japanese workers on early develo ment and propagation of *C. gigas* are reviewed at length by Cah (1950). We may add to this review the articles of Hori and Kusaka (1926) describing their successful efforts in growing larvae of *C. giga* More recently, Imai and Hatanaka (1949) and Imai *et al.* (1950b) gre larvae of these oysters on a much larger scale.

Our experience with *C. gigas* received from the State of Washingto showed that their spawning behavior, egg development and the shap of their larvae seem to be identical to those of *C. virginica* (Fig. 35 The similarity in shapes and sizes of the larvae of these two specie is so great that we doubt if even an experienced investigator, famili with both species, would be able to differentiate them in a mixe sample.

The general behavior, food requirements and growth rate of larvae '. *gigas* also appear to be identical to those of larvae of the American ster. Even the size of the eggs and the size at which larvae of the species begin to metamorphose are alike. A comparison of the gth-width relationship of larvae of the two groups will still further licate their similarity. Yet, regardless of this similarity, the attempts Davis (1950) and Imai *et al.* (1950b) to hybridize these two species re unsuccessful. Although fertilization occurred and the larvae veloped into veligers, they all died before reaching metamorphosis.

Gonad development and spawning of Japanese oysters kept at ilford have not been as thoroughly investigated as those of the nerican oyster. Nevertheless, there appear to be several important fferences. First, Japanese oysters require higher temperatures to gin spawning. Groups of these oysters kept in the laboratory all mmer did not spawn, although the temperature at times was over °C. Furthermore, *C. gigas* either does not resorb the gonad material at remains undischarged at the end of the spawning season or does at a much later date and at lower temperatures than *C. virginica*. apanese oysters, brought to Milford from Puget Sound in October ith undischarged gonads, held this material far into the winter and ctive sperm was found in some oysters late in December.

In our waters growth of post-setting stages of Japanese oysters much more rapid than that of the local species. *C. gigas* that set n the laboratory in the spring and then were planted in Milford Harbor were 2½ to 3 in long by the end of the growing season, while native oysters, which had set at the same time and were grown under identical conditions, were only 1 to 1½ in long.

K. *Laevicardium mortoni* (Conrad)

This bivalve, which is called *Cardium mortoni* by some authors and is also known as Morton's cockle, is quite common in the comparatively shallow waters of Long Island Sound. If brought into the laboratory in late January and conditioned at temperatures between 15° and 20°C for several weeks, these cockles are easily induced to spawn by temperature stimulation alone. On several occasions spawning of ripe cockles began in less than 5 min after the water temperature was raised only 1° or 2° above 20°C. The majority spawned within ½ hr and, as a rule, all began spawning before the water reached 30°C. Some cockles spawned at least three times during a single week.

The hermaphroditic cockles often acted first as males and then as females in the same spawning. Sometimes, after first discharging sperm, they released large quantities of eggs and finally ejected sperm again. Probably because of this condition, which resulted in lar quantities of sperm in the spawning dishes, many cases of polysper were seen.

The eggs of *L. mortoni* measure from 60 to 65 μ in diameter. Lov (1848) reported that eggs of the related species, *Cardium exiguum*, ha a diameter of 64 μ and are deposited in a thick gelatinous man within which development goes on until the shell-bearing veliger h attained a length of 90 μ. Orton (1924), who performed success artificial fertilization of a closely related species, *Cardium fasciatu* and Jørgensen (1946) reported that eggs of that bivalve measu about 80 μ in diameter, thus being considerably larger than those our species. In still another closely related form, *Cardium edu* according to Lebour (1938), the egg diameter is only 50 μ.

The smallest normal straight-hinge larvae in our cultures measur about 85 × 70 μ. Sullivan (1948) stated that very small larvae *Cardium pinnulatum* are 90 × 80 μ, a size closely corresponding our smallest normal larvae. In early stages the margin of the lar shell is outlined by a dark band, similar to that seen in *Teredo* larva but not quite as prominent. Usually, one end of the shell is slight more pointed than the other.

The umbo begins to appear when larvae are between 135 a 150 μ in length and is usually quite prominent when a length of abo 160 μ is reached.

The larvae were grown at room temperature of about 20°C and f a mixture of *I. galbana* and *M. lutheri*. The first metamorphosi individuals were observed 8 to 10 days after fertilization. The smalle individual, having a definite foot but no velum, measured only 205 while the largest swimming larvae with a still well-developed velu measured 245 μ. Some metamorphosed cockles with well-develop gills and a siphon were only 220 μ long. No " eye " was observed any of the larvae.

The size of the largest swimming larva ever recorded in o cultures was 250 × 220 μ, but only one such individual was seen. T maximum size of our larvae, therefore, closely agrees with th described by Sullivan (1948) for *C. pinnulatum*, which measur 250 × 230 μ. Jørgensen (1946) mentioned that Lebour grew larv of *Cardium echinatum* which, at metamorphosis, measured about 480 in length. We accept this figure with considerable reservatio Jørgensen also assumed that the maximum length of larvae *C. exiguum* is about 250 μ, although he never observed this velig with certainty in the Sound, where he carried on his experiments. H observation on *C. fasciatum* indicated that the largest larval stag his species found in plankton were about 300 μ long. However, he ed that the veliger may leave the plankton at a length of about μ, which is not too different from our maximal size.

Jørgensen (1946) also offered extensive observations on the length arvae of *C. edule*. He stated that in rearing experiments at Kristine- g the length at metamorphosis varied from about 275 to 345 μ. ngth measurements of prodissoconchs in oyster ponds near Limfjord ied from 200 to 275 μ, averaging 240 μ. Jørgensen was under the pression that larvae of this species are distinguished by an excessive riation in size at the time of metamorphosis. This condition coincides th our observation that usually in cultures of larvae approaching tamorphosis there is a great variation in size. For example, in our ultures of *L. mortoni*, while some of the larvae had already set and thers approaching metamorphosis measured 245 × 205 μ, the smallest ndividuals in the same culture, grown under identical conditions, were nly 140 × 120 μ.

IG. 36. Larvae of *Mercenaria campechiensis*. Largest larvae are approximately 185 μ long.

L. *Mercenaria* (= *Venus*) *campechiensis* (Gmelin)

These clams, commonly known as southern quahogs, were brought o Milford from the Gulf of Mexico, near Apalachicola, Florida. lthough they appear to differ somewhat from northern quahogs, *ercenaria* (= *Venus*) *mercenaria*, their spawning behavior and appear- nce of their eggs and larvae are identical and, therefore, they will ot be described (Fig. 36).

On several occasions groups of *M. mercenaria* and *M. campechiensis*

were conditioned for spawning and later induced to spawn sin
taneously but in separate dishes. The eggs obtained from th
spawnings were cultured under identical conditions. Observati
showed that egg development and rate of growth of larvae of th
two species were virtually identical throughout the experiment a
that metamorphosis in both groups began at the same time.

Reciprocal crosses of the two species produced viable larvae, wh
grew to metamorphosis; at times these hybrids showed somewh
more rapid growth, possibly as a result of hybrid vigor. Many of the
hybrids have been grown to maturity in several locations along
South Atlantic coast and also in the Gulf of Mexico, but not in c
areas, such as Milford Harbor, where the low water temperature
winter usually caused their death.

M. *Tapes semidecussata* Reeve

T. semidecussata is one of the most important commercial spec
of clams in Japan, where it is known under the common name of Asa
It was accidentally introduced to our Pacific coast when Japan
oysters, *C. gigas*, were brought there early in the century. It spre
rapidly and is now one of the most important species of clams in t
State of Washington, where it is called the Japanese little neck,
Manila clam. In the literature *T. semidecussata* appears under a varie
of names, including *Venerupis semidecussata*, *Venerupis philippinaru*
Paphia philippinarum, *Tapes japonica*, and others.

The first group of *T. semidecussata* was received in Milford fr
Puget Sound in December 1955. Upon arrival the clams were co
ditioned at about 20°C for 2 to 3 weeks and then induced to spaw
Cultures of larvae were successfully grown from January until t
end of the summer. According to Cahn (1951) the spawning peri
of *T. semidecussata* of the Hokkaido region of Japan extends fr
June to late August, when the water temperature is between 2
and 23°C.

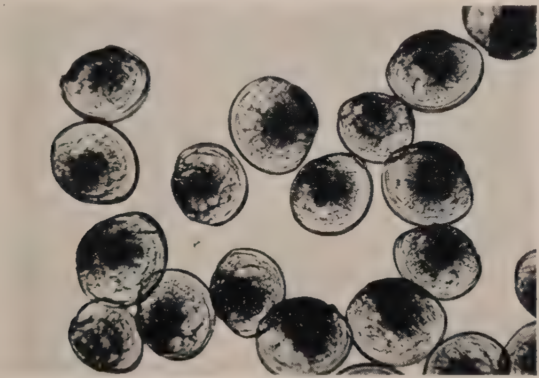
In our spawning experiments ripe clams quickly opened and pump
vigorously when the temperature of the water was increased to abo
25°C. However, raising of the temperature even to 30°C was oft
insufficient to induce spawning, and addition of sperm or egg suspensi
was usually necessary. Even then, on some occasions, although th
gonads were filled with mature gametes, the clams did not respo
to the combination of stimuli.

Spawning usually occurred at temperatures between 20° a
27·5°C. The act of spawning closely resembled that of *M. mercenari*

rm or eggs were released in a constant stream from the excurrent hon, sometimes continuously for 30 min or longer.

Eggs of *T. semidecussata* range from 60 to 75 μ in diameter, in- ding the transparent membrane around the eggs that measures m 5 to 10 μ in thickness. The average diameter of the egg, including membrane, is approximately 69·6 μ. According to Cahn (1951) panese workers found that eggs of this clam measured between and 66 μ in diameter with a perivitelline space measuring from to 4·6 μ in width and surrounded by a gelatinous coating approxi- tely 23 μ in thickness.

Most of the cultures of *T. semidecussata* were grown at room tem- rature. They were fed a variety of algal cultures, but no systematic tudies of their food preference were made. Nevertheless, it was oticed that, while sometimes they grew well on mixed green algae onsisting mostly of *Chlorella*, at other times, when given practically the same food, growth was poor. When given a mixture of *Chlorella* sp. and *P. tricornutum*, their growth also varied on different occasions. When fed *Chlorococcum* sp. the larvae usually grew well. Best growth was achieved when they were given *I. galbana* or *M. lutheri*.



IG. 37. Larvae of *Tapes semidecussata*. Largest larvae in photomicrograph are approximately 175 μ long.

Very early stages of straight-hinge larvae of *T. semidecussata* are remarkably similar to those of *M. mercenaria*. Some of the smallest straight-hinge larvae in our cultures were only about 90 μ long, but such individuals were uncommon; the majority measured approximately 95 × 70 μ. The umbo begins to develop when the larvae are approximately 120 μ long and becomes fairly prominent by the time

the larvae are about 140 μ in length although, even then, the hi
line may appear straight when seen from certain angles. As the larv
grow, the umbo becomes more prominent and in older larvae it
somewhat more pronounced than in *M. mercenaria* (Fig. 37).

When fed *Chlorella* sp. larvae reached metamorphosis in ab
2 weeks. However, by giving them better food, such as naked fla
lates, and by increasing the temperature of the water, setting size co
be reached several days earlier.

The smallest metamorphosed individuals with a large, functio
foot and fully resorbed velum measured about 175 μ in length, or ab
the same as that reported for *M. mercenaria*. The majority of the larv
metamorphosed when they were between 200 and 220 μ in length, b
some much larger larvae measuring about 235 μ in length still posses
a functional velum and were able to swim. Yoshida (1960) gave t
size of fully grown veligers of *T. variegata* as 215 × 195 μ.

As in most of our larval cultures, the color of the larvae depend
to a large extent, upon the food given. Furthermore, differences
size among larvae of the same cultures were of about the same mag
tude as in cultures of other species. It has also been definitely establish
that larvae of *T. semidecussata* are susceptible to fungus diseases.

Because of our prolonged studies of *T. semidecussata* we have h
an opportunity to observe their adaptability to changes in th
surroundings. These clams were able to survive considerable variatio
in temperature and salinity, which occur over the tidal flats of Milfo
Harbor in front of our laboratory. During one winter, when the te
perature of the water remained below zero for several weeks and t
shores were covered with a thick layer of ice, only about 3% of t
clams planted on the flat, near the mean low water level, died. T
clams also survived periods of freshets, such as were caused by hurrica
"Donna" in 1960, when salinity of the water in Milford Harbor w
reduced almost to zero and remained low for several days.

The clams spawned and their larvae set normally in our expe
mental ponds. The small clams grew to a size of about 1 cm by t
middle of September.

N. *Pitar* (= *Callocardia*) *morrhuana* Gould

This small mollusk, which somewhat resembles *M. mercenaria*,
found along the northern section of our Atlantic shore, roughly fro
Prince Edward Island to Cape Hatteras. In some sections of this rang
as in Narragansett Bay, it is quite numerous.

Recent literature contains few references to propagation or larv ges of *P. morrhuana*. Sullivan (1948) is virtually the only author devote some attention to veligers of this bivalve. Costello *et al.* 57), calling the same form *Callocardia convexa*, gave a good description of procuring gametes of these mollusks.

Our own experience with *P. morrhuana* has been extensive but not vays satisfactory because this clam is one of the few bivalves that could not induce to spawn. All the methods known to us, including reasing of the water temperature, addition of ripe sex products, anges in pH or salinity, and use of mechanical and electrical stimu-ion failed to induce spawning. Moreover, we have never observed tural spawning among the hundreds of these clams that have been pt in our laboratory under different conditions, sometimes for periods several months.

Animals brought into the laboratory from their natural beds in nuary already contained what appeared to be morphologically-ripe metes. The color of the female gonad was usually creamy white d that of the male a light yellow. Even this early in the season tive sperm could be taken from male gonads. The spermatozoa sembled those of *M. mercenaria* in shape. Eggs could be easily tained by stripping, but they could not be fertilized so early in the ason. This was true even when *P. morrhuana* was slowly conditioned the laboratory by day-by-day increases in temperature. However, the season progressed, the eggs became more responsive and the rminal vesicle in some of them dissolved soon after introduction of ermatozoa.

Our larval cultures were grown from eggs obtained by stripping. he size of the eggs taken from females with well-developed gonads nged in diameter from 49 to 60 μ, with the modal size-group between 0 and 55 μ. These measurements, however, refer only to the egg roper; if the entire diameter of the ovum, including its thick, gelainous membrane were measured, it would vary between 92 and 128 μ, ith the modal class near 117 μ.

On several occasions we tried to improve the condition of stripped ggs by adding 3 ml of 0·1 N ammonium hydroxide to every 100 ml of gg suspension. After 25 min of this treatment the eggs were screened o discard the fluid. The eggs were then rinsed with sea water, resusended, and spermatozoa added in proper quantities. In some instances, fter this treatment about 40% of all eggs underwent cell division, but sually not more than 5% developed to normal straight-hinge larvae.

Early development of eggs and larvae of *P. morrhuana* is virtually dentical to that of other mollusks of the same group. Progress of evelopment, as usual, depends upon the temperature at which the organisms are grown. In some cases straight-hinge larvae were form after 24 hr at a temperature of about 21°C.

The size of the smallest normal straight-hinge larvae was appro- mately 78 × 64 μ. Several smaller larvae measuring only 75 μ i length were also observed, but appeared to be abnormal. Some lar began developing an umbo when 95 μ long, and the major possessed a well-developed umbo by the time they reached a len of 125 μ. No "eye" spots were observed in either larvae or recen set juveniles. Larvae of *P. morrhuana* closely resembled those f *M. mercenaria*, but were considerably less active (Fig. 38).

Metamorphosis occurred when the larvae were still comparativ small. The smallest young clam possessing a functional foot a attached by a byssus thread measured only 160 μ. However, a major of the larvae did not begin to metamorphose until reaching a len h of approximately 180 μ. The largest free-swimming larvae still p sessing a functional velum measured 192 × 179 μ.

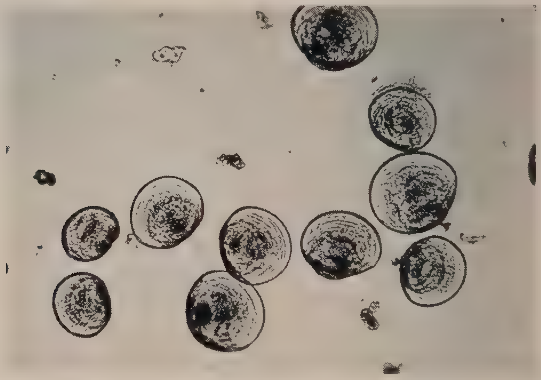


FIG. 38. Larvae of *Pitar morrhuana*. Largest larvae shown are approximately 1 μ long. Small, abnormal larvae can be seen in the group.

According to Sullivan (1948) the smallest larvae of *P. morrhua* were 120 × 95 μ. This size is considerably larger than that of e smallest larvae in our cultures. The maximum size offered by Sulliv , 220 × 210 μ, was much larger than ever recorded in our cultur . It seems improbable, therefore, that the larvae considered by Sulli n to be those of *P. morrhuana* were actually of this species.

Growth of larvae in different cultures varied considerably, depe - ing upon temperature and quality of food given. The majority of e cultures fed a mixture of plankton, composed mostly of several spec s

Chlorella, and kept at room temperature began to set about 14 days er fertilization. Probably if given better foods, such as *I. galbana* d *M. lutheri*, which at the time of rearing *P. morrhuana* were not ailable at our laboratory, a better rate of survival and growth could ve been achieved.

Many cultures suffered mass mortality, which usually occurred ring the late stages of larval growth. These mortalities were probably used by the same fungi that were later found responsible for heavy ortalities of larvae in cultures of *M. mercenaria* and several other ecies.

O. *Petricola pholadiformis* Lamarck

Even though the range of this clam extends from Prince Edward land to the West Indies and Texas and their larvae should be common plankton samples during the reproductive period, Sullivan (1948) ems to be the only author who has described them. According to is author the first larvae of *P. pholadiformis* normally appear in the aters of Malpeque Bay, Prince Edward Island, about the 2nd week f July and, after reaching peak numbers in early August, disappear om plankton in early September.

In our laboratory, groups of *P. pholadiformis* were conditioned r spawning from the middle of December until summer. In the early inter these efforts were not as successful as later in the season and onditioning required a much longer time. For example, clams placed conditioning trays at about 20°C in December required 4 to 6 weeks efore the majority responded to stimulation and spawned. In the iddle of April, however, only a week of conditioning at about 20°C as sufficient to bring these clams to spawning condition.

Conditioned clams were induced to spawn by our usual method, onsisting of subjecting them to a quick increase in the water temperaure from about 20° to 27°C and by the addition of a sperm suspension. ater in the season spawning, especially of males, could be induced on ome occasions at a temperature as low as 15°C. Raising the water emperature to about 32°C always affected clams unfavorably.

Early in the season several hours at the increased temperature were often required before the first individuals, usually males, would respond, whereas late in March and in April spawning was usually provoked within the first hour. Even young clams, less than 1 yr old, and individuals with partially damaged shells responded to stimulation and discharged large quantities of spawn. Often the same individual would spawn for a while, cease spawning and then resume it. Many individually-marked clams spawned several times during the season.

Attempts at artificial fertilization of eggs of *P. pholadiformis* w partially successful, indicating that this can be done. As usual in th cases, the majority of stripped eggs were somewhat injured.

Ripe eggs measured immediately after discharge varied in diame from 51 to 58 μ, but the modal size was quite clearly defined at 52 No special studies were made as to the number of eggs produced b single female during the season. However, in one case a large fem discharged approximately 1 125 000 eggs in a single spawning.

According to Sullivan (1948) straight-hinge larvae of *P. pho* *diformis* are quite large, measuring 115 × 100 μ. We found, howev that young straight-hinge larvae are considerably smaller than report by Sullivan. With the exception of one, apparently an abnormal lar which measured approximately 71 × 67 μ, the majority of norma formed young larvae were 79 × 65 μ in size. The largest free-swimmi larva was about 193 × 174 μ, although many underwent metam phosis before reaching this size, being approximately 186 × 164 (Fig. 39). These dimensions are somewhat larger than indicated Sullivan (1948).

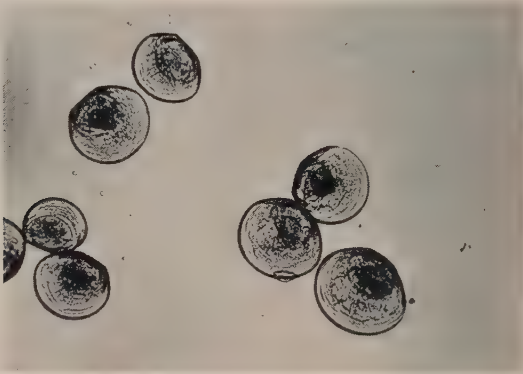


Fig. 39. Larvae of *Petricola pholadiformis*. Largest larva in this photomicrograp about 164 × 143 μ.

Early straight-hinge larvae are very light in color and even th digestive organs are comparatively pale. In general, they are m transparent and thinner than larvae of most of the species describ in this paper. Some of them remain transparent up to the time metamorphosis. However, when given purple sulphur bacteria belo ing to the genus *Chromatium*, larvae quickly acquire a pinkish col If they are given such foods as *Chlorella*, their digestive glands rapi become a greenish color.

Since studies on larvae of this species were carried on when good od organisms, such as the naked flagellates, were not available, the rvae were fed mixed cultures of microorganisms in which *Chlorella* s usually the predominating form. Larvae grew well on this alga, though it is quite certain that they would have grown faster if given tter foods.

Larvae of *P. pholadiformis* were grown at temperatures ranging om 18° to 30°C. The best cultures were observed at room temperatures nging from 20° to 25°C. At somewhat lower temperatures, between ° and 18°C, eggs developed and larvae grew, but growth was slow. t 30°C egg development was rapid, but larvae were feeble and the ajority died within 2 to 4 days. Perhaps mortality was not due xclusively to temperature alone, but to the heavy bacterial flora that uickly established itself under these conditions.

The shortest period from fertilization of the egg to metamorphosis room temperature was 13 days. In several instances, however, the rvae of these cultures did not begin to set until the 20th or 21st day. he differences were probably due to variations in quality and quantity f food.

Two characteristics were noticeable in young clams soon after etamorphosis. First, the color of their shells becomes much denser nd, secondly, the edges of the shells opposite the umbo acquire a errated, roughened appearance.

P. *Ensis directus* (Conrad)

The general characteristics of larvae of *E. directus* were given ecently by Sullivan (1948). Costello *et al.* (1957) gave a brief description of early stages of egg development, while Lebour (1938) had studied arvae of *Ensis siliqua*. In general, however, larvae of *E. directus* ave been less intensively studied than those of other common bivalves of our coast.

In our laboratory, observations on *E. directus* and its larvae were onducted for three winters. Each year these clams were brought from the field and placed in conditioning trays in late December. It was found, however, that when these clams are removed from the soil they soon begin to die because the powerful hinge pulls the clam shells apart. This can be prevented by placing tight rubber bands around each clam to counteract the action of the hinge and keep its shells closed. Using this simple method these clams have been kept alive without any soil for periods as long as 6 months.

Attempts to induce spawning of *E. directus* were made during the middle of January after 2 or 3 weeks of conditioning. Although at that time their gonads contained some eggs that appeared morpl logically ripe and active sperm, the clams would not spawn. Ev after 6 or 8 weeks of conditioning, attempts to spawn these bivalv often met with failure. In those cases, however, when stimulation w successful, spawning proceeded normally. Some females were observ spawning almost continuously for a period of approximately 45 mi and males that spawned for periods sometimes as long as 2 hr we common.

When the clams were ripe they usually spawned within an ho after the temperature was increased to about 25°C. Males continu to spawn profusely even after being returned to water of only 13° Clams became sluggish at 30°C but, nevertheless, would spawn ev

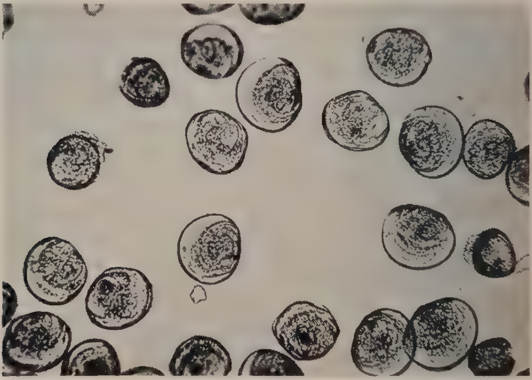


Fig. 40. Larvae of *Ensis directus* grown from eggs obtained by stripping. Note th many larvae are abnormal. Largest normal larvae shown are about 125 μ long.

at this temperature. Spawning activity was definitely accelerated b the presence of sperm. Both males and females released gametes in thin, steady stream from the excurrent siphon.

Several clams spawned at least three times, at weekly interval The greatest number of eggs released by one female in a single spawnin was 12 585 000. The greatest number of eggs released by one fema in three spawnings was 20 535 000.

Unprovoked spawning of razor clams kept in conditioning tra occurred on many occasions. It took place at temperatures rangin from about 15° to 22°C. It has not been determined what stimul induced spawning in those instances. Histological studies showe that on many occasions gonads were almost completely spent in single spawning effort.

Success of fertilizing eggs stripped from conditioned females de- nded upon the degree of their ripeness. Early in the season, when e largest of the eggs were only 66 μ, none were fertilizable. Later, nen the clams were riper, a large percentage of stripped eggs under- nt cleavage but, as is often the case in using eggs obtained in this anner, most of the larvae were abnormal (Fig. 40). Costello *et al.* 957) also reported that eggs of *E. directus* can be fertilized artificially nd they remain fertilizable for about 5 hr.

The egg of a razor clam is surrounded by a narrow perivitelline pace enclosed in a thin vitelline membrane. Measurements of eggs ischarged in a normal spawning showed that they varied in diameter om about 64 to 73 μ, the majority being 71 μ, thus indicating that is is the modal size of normal eggs. Lebour (1938) gave the diameter f eggs of *Ensis siliqua* as about 70 μ, which closely resembles measure- ents of eggs of our species. Jørgensen (1946) gave references to other orkers who studied eggs and larvae of *Ensis* and related forms.

Eggs and larvae were usually cultured at about 22°C. The smallest traight-hinge larvae were 80 μ in length, but only two individuals his small were observed. Even larvae as small as 85 μ in length were carce, while those measuring approximately 92 × 78 μ were common. his size is considerably smaller than the 140 × 120 μ indicated by ullivan (1948) as the smallest larvae of this species.

The larvae are light in color and more transparent than those of *M. mercenaria*. The umbo appears in larvae only 115 μ in length and ecomes well developed in larvae 135 μ long. Larvae of this size have efinitely passed the straight-hinge stage. The umbo is so pronounced n larger larvae that it is impossible for them to lie flat. As a result, onsiderable variation in the length–width ratio is obtained when arge larvae are measured under a microscope.

Setting of *E. directus* began soon after some larvae reached a length f about 210 μ. At 24°C this often occurred only about 10 days after ertilization. However, some larvae remained swimming until they eached a much larger size before undergoing metamorphosis. For xample, in one culture fed *Chlorella* sp. larvae measuring 250 to 260 μ n length were still swimming 27 days after fertilization and possessed both a powerful velum and a well-developed foot. The largest swimming larva measured 270 μ, while in the same culture many fully metamorphosing individuals showing a well-developed foot, gills and siphons were only 220 μ long.

The appearance of the "eye" was irregular and it was not located where this structure is usually found in most bivalve larvae. The smallest individual possessing this structure was only 126 μ long, but many other larvae, even those nearing metamorphosis, did not displ it. Sullivan (1948) did not mention the presence of an “ eye ” in *directus* larvae and Werner (1939), working with a species that called *Cultellus pellucidus*, a form closely related to *Ensis*, stated th its larvae do not possess “ eyes ”. This observation is quite importa because, according to Rees (1950), the description by Werner *C. pellucidus* was really that of *Ensis*. Our observation that t “ eye ”-like structure is sometimes present in larvae of *E. direct* and Werner’s, that it is always absent in the species that he studie may indicate that Rees’ assumption is not correct and that th *C. pellucidus* of Werner was not an *Ensis*.

One of the characteristics of larvae of *E. directus* which may be diagnostic value is the presence of a clear area around the edge of t shell. This area, which does not occur in larvae of other species th we have studied, is well defined and clearly seen. It appeared in larv of about 120 μ long and persisted until they reached a length of 1 to 190 μ. Later this area became less definite and more or less merge with other parts of the shell. Near setting, however, a purple ca became apparent along the edge of the larval shell.

In rearing of *E. directus* the presence of many abnormal larva was quite common, not only in cultures that were started from strippe eggs, but also in those that were grown from normally discharged one

In several cultures, usually those where larvae were approachin setting stage, mortalities on an epizootic scale were recorded. I several instances practically all of the larvae died within a short perio usually less than one day. Since this happened before we learned th devastating effect of larval diseases caused by fungi or bacteria, w did not establish the cause of death of these larvae but strongly suspe that these mortalities were principally the result of fungus infestation

Q. *Mactra* (= *Spisula*) *solidissima* Dillwyn

The clams used in these studies were taken from the sandy beache of the south shore of Long Island, New York. They were shipped t Milford and kept for many months, either in the laboratory or in th harbor, without any appreciable mortality, although the salinity a Milford is about 27 ppt, or approximately 8 ppt lower than in th areas where the clams were dredged. The clams survived equall well whether they were allowed to dig into sand or were kept in wi baskets containing no soil. To prevent mortality, however, it wa necessary to expel bubbles of air which were trapped inside the clam while they were out of water. Clams placed on their sides cannot exp these bubbles and, eventually, die.

Our experience in growing larvae of *M. solidissima* was confined the period from the middle of January to the end of June. During at time morphologically-ripe eggs and spermatozoa were always sent in the gonadal follicles. Possibly, equally well-developed cells could have been found in the gonads several weeks earlier n January because, apparently, the most important period of metogenesis in *M. solidissima* begins immediately after the end of wning, as in *M. mercenaria*, in which gonads of both sexes present a pe appearance in December (Loosanoff, 1937b). Allen (1953) obtained pe eggs of *M. solidissima* from early spring until late autumn.

Spermatozoa, taken from clams brought from their natural beds rly in January, when placed in a drop of water at room temperature ickly began to move. However, eggs taken from clams of the same oups usually could not be fertilized, probably because they were not ysiologically ripe. Nevertheless, placing female clams in water of out 15°C for only a few days was sufficient to ripen them. Later in e season, when the temperature of the water in Milford Harbor creased to 12°C, no conditioning was needed.

Fertilizable eggs could be obtained either by stripping or by inducing awning. Sometimes, stripped eggs obtained from a ripe female were viable as those discharged during a normal spawning. More often, owever, a culture started with stripped eggs contained many abnormal dividuals. Costello *et al.* (1957) suggested a different method of btaining gametes, which consisted of straining the eggs through a heesecloth.

Spawning was induced by the usual method of thermal and chemical timulation. On several occasions thermal stimulation alone was ufficient. Normally, addition of a suspension of sex cells was required nd, even then, many conditioned clams did not spawn.

Spawning was induced at temperatures ranging from 18° to 25°C. emperatures of 30°C and over unfavorably affected the clams. They aped and abnormally extended their feet which, like the rest of heir bodies, became limp and soft. If, after exposure to such high emperatures the clams were quickly returned to cooler water of bout 25°C, they often began to spawn, but the eggs obtained in such manner did not develop past the formation of polar bodies. Apparntly, exposure of clams to temperatures over 30°C caused serious njuries to their eggs. Our observations in this respect agree with those f Imai *et al.* (1953) who, while working on a closely-related species, *Mactra sachalinensis*, found that at a temperature of about 32°C none of the eggs underwent normal cleavage.

Observations were made on the growth of larvae of *M. solidissima* at two different temperatures. Eggs obtained from several femal and fertilized with spermatozoa of three ripe males were mixed togeth and then divided into two groups, one to be grown at a temperatu of about 22°C and the other at 14°C. The concentration of eggs per of water was the same in both cultures. During the experiment t larvae were fed equal quantities of phytoplankton composed larg of *Chlorella* sp.

Eggs placed in water at 14°C were in the trochophore stage at t end of 40 hr. After 72 hr the culture contained normal and acti straight-hinge larvae averaging 85 μ in length, which were qui uniform in size and appearance. At 22°C this stage was reached aft only 28 hr. Young straight-hinge larvae of *M. solidissima* were usual

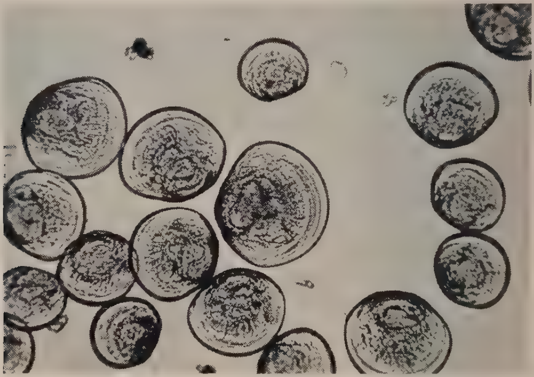


FIG. 41. Larvae of *Mactra solidissima*. Largest larva, 219 μ long and 193 μ wide, approaching metamorphosis. Note differences in sizes of larvae that originat from the same group of eggs and were reared under identical conditions.

almost transparent and had a granular appearance with the intern organs at this time not too well defined. Later, as in the case of mo larvae, the color began to deepen.

On the 19th day, when larvae in the warmer culture began metamorphose, the length of the modal class of larvae grown at 14 was only 117 μ, and the larger individuals in the cultures were onl 153 μ long. The first metamorphosing clams were observed in th culture after 35 days. When the experiment was discontinued on t 50th day the remaining larvae showed a wide range in size, the smalle being only 109 μ long (Fig. 41).

A partial description of development and dimensions of larv of *M. solidissima* was given earlier in this article. Here we may ad t the most recent description of what were assumed to be larvae *Mactra* (= *Spisula*) *solidissima* was reported by Sullivan (1948). She ve the minimum size of straight-hinge larvae as about 95 × 80 μ, ich is approximately 15 μ longer than usually found in our cultures, ile the maximum size of 270 × 245 μ closely agreed with our asurements. In both instances the length–width relationship given Sullivan falls near the median line of length–width relationships ich we found for larvae of *M. solidissima.*

In describing larvae of a related form, *Spisula subtruncata*, Jørgen-n (1946) reported that veligers are about 400 μ at the time of etamorphosis. Kändler (1926) stated, however, that the length of is species at metamorphosis is only 310 μ. Considering that Imai *al.* (1953) found the maximum size of larvae of *Mactra* (= *Spisula*) *chalinensis* to be about 270 μ, virtually the same as we found for *. solidissima*, and because Imai's conclusions and ours are based on easurements of larvae of a known origin, we think that Kändler's easurements are more realistic than Jørgensen's and that the latter as probably describing larvae other than those belonging to the genus *actra* (= *Spisula*). The same consideration leads us to believe that the escriptions and measurements offered by Rees (1950) of advanced ages of larvae presumably of the superfamily Mactracea, including *pisula solida* (360 μ) and *Spisula elliptica* (355 μ), are really those of me other species.

R. *Mya arenaria* Linné

Our efforts to induce spawning of *M. arenaria* were confined largely the period extending from March until the middle of July. Several roups of these clams were also conditioned and spawned in winter. oreover, to induce spawning of even well-conditioned and apparently ipe *M. arenaria* is difficult, nevertheless.

In developing a method to induce spawning of these clams we tried any approaches, including sudden and gradual changes in water emperature, changes in pH, salinity, hydrostatic pressure, light ntensities and the addition of sex products. Usually, none of these orked. The only method that proved to be successful with some egularity consisted of subjecting ripe clams to water of relatively igh temperature, of about 26° to 28°C, for long periods often extending rom 6 to 8 hr and adding, during this time, a suspension of sex products. Many clams spawned profusely when this method was employed nd discharged a large number of eggs, but a high percentage of these ggs usually developed into abnormal larvae.

Belding (1931) reported the diameter of the average egg of the soft shell clam as 62·5 μ, while Battle (1932) gave the egg size as varyi from 70 to 80 μ. Our measurements of hundreds of eggs discharg by different females and on different occasions showed that the majori were between 68 and 73 μ in diameter, with a modal size of 70·5 μ.

Belding (1931) expressed the opinion that artificial cultivation *M. arenaria* is virtually impossible because the eggs either fail develop normally or else never pass the young veliger stage. Neve theless, Belding was able to show that, unlike other pelecypods, eg stripped from *M. arenaria* can be artificially fertilized.

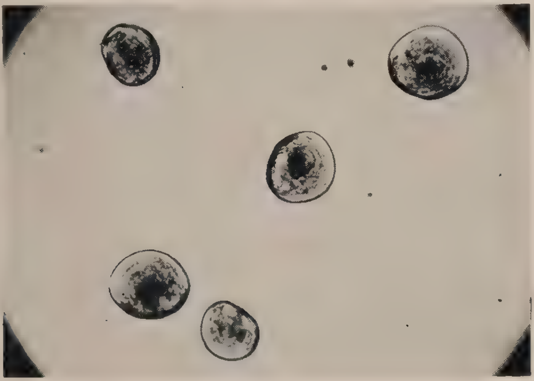
The smallest normal straight-hinge larvae recorded in our cultu measured only about 86 × 71 μ. These were, however, extreme uncommon and normal, fully-formed straight-hinge larvae we usually about 93 × 77 μ. As in most pelecypod larvae, they were lig in color at this stage and their internal organs were not well define They remained quite light, almost transparent, until a length of abo 110 μ was reached. As the larvae grew, they became darker. Neve theless, as mentioned on several occasions, these larvae do not posse characteristic colors that would help to distinguish them from membe of other genera or species of bivalves. In our experiments, whe larvae of this species were fed different foods, their color ranged fro a dark reddish-brown to dark green. We cannot, therefore, agr with Sullivan (1948) that brown pigmentation in large larvae of *M* *arenaria* is diagnostic of that species.

In older larvae measuring about 175 μ and longer we noticed t presence, in the margins of the mantle, of irregular opaque spo varying in size from 5 to 15 μ. These granules occurred with su regularity that we are inclined to consider them as characteristic the species, at least during late larval stages. Jørgensen (1946) notic a somewhat different pigmentation of the soft parts of larvae *M. arenaria* measuring about 200 μ and larger. He also suggested th this may be a reliable specific character.

The size of larvae of *M. arenaria* at setting is extremely varie Metamorphosis may occur at any length from 170 to 228 μ. The latt is the size of the largest free-swimming larva ever recorded in o cultures. The majority metamorphosed at a length between 200 a 210 μ.

The smallest larva in which the foot was present was about 165 long but many of the larvae had a well-developed foot by the time th reached 175 μ in length. The presence of a large foot does not nece sarily indicate that the velum has already become non-function Larvae as long as 210 μ have been seen at times swimming about usi both the velum, which still appeared to be of normal size, and al large foot. However, the velum normally begins to disappear n after a length of 172 to 175 μ is reached and sometimes even lier. In most individuals 200 μ in length the velum is already orbed. Some larvae measuring only 175 μ in length, and having no um, were seen actually crawling, using their feet.

The balancing organ, the otocyst, can be clearly seen at the base the foot of larvae measuring about 175 μ in length. The byssus nd also can be seen in larvae less than 200 μ in length, and the ls may be clearly discerned in some individuals of about the same e. The byssus thread is strong, and our attempts to break it by ecting a strong jet of water from a pipette caused the larvae to ay from side to side, but did not break the thread.



IG. 42. Young larvae of *Mya arenaria*. Largest larva shown is about 140 μ long.

No systematic studies on the rate of growth of larvae of *M. arenaria* t different temperatures, such as those conducted with larvae of *I. mercenaria*, were made. Our attempts to grow larvae at low temperatures ranging from 12° to 15°C were usually unsuccessful because f slow growth. For example, at a temperature of about 14°C larvae, ven after 15 days, were only about 110 to 115 μ long. Larvae grown at w temperatures, probably because of the slow rate of growth, were sually of extremely uniform size.

Most of our cultures were grown at room temperatures which anged from about 19° to 24°C. Under those conditions the rate of rowth was quite rapid, although it varied, of course, from culture o culture, depending upon the temperature, concentration of larvae, nd quality and quantity of food given. At about 23°C the average ength of larvae 2 days after fertilization was approximately 109·5 μ

and the maximum 117 μ. After 5 days larvae averaged 120 μ in len
and the largest individuals were 140 μ long (Fig. 42). After 10 d
some of the largest larvae approached a length of 180 μ at wh
setting is possible. By the 15th day many individuals had alrea
set, and the average size of the larvae in the cultures had increa
to about 175 μ. A few large larvae, measuring about 225 μ in len
but still free swimming, were also found in our samples. In so
cultures setting began when the larvae were about 10 days old a
continued until the end of the 35th day.

As has already been mentioned, the smallest straight-hinge larv
of *M. arenaria* in our cultures measured about 86 × 71 μ. The larg t
free-swimming individuals were 228 × 207 μ, although most of th
metamorphosed before that size was reached. Our measuremen
therefore, differ from those given by Stafford (1912), who stated th t
the smallest straight-hinge larva of *M. arenaria* that he found was o
75·9 × 62 μ, while the largest measured 414 × 345 μ. Of the lat r
he said, "The largest measurement I have is 64 × 53, and I ha
seen them attached by a byssus-thread, their siphons protruded, a
the big hinge-tooth on the left valve." Since, according to Staffo
each unit of his measurements was equal to 6·9 μ, the dimensions f
his larvae were as given above. It is quite possible, if his measureme s
were correct, that Stafford was working with larvae of a species oth r
than *M. arenaria* and, possibly, his large individuals were alrea
juvenile mollusks and not free-swimming larvae. Another possibil
is that Stafford's microscope was not correctly calibrated.

The dimensions of larvae in our cultures were not too differe t
from Sullivan's (1948). Nevertheless, her smallest size of 105 × 9
is considerably larger than we found and her largest, 250 × 230
also somewhat exceeds ours. Yoshida's (1938) observation that larv e
of *M. arenaria* in Japanese waters metamorphose upon reaching a s e
ranging from 240 to 300 μ also disagrees with ours because, while t e
length of 240 μ does not differ radically from the measurements of r
largest larvae, the maximum size of 300 μ given by Yoshida excee s
ours by about 70 μ.

The length of early straight-hinge larvae of *M. arenaria* given
Jørgensen (1946) is similar to ours. This is to be expected because s
early larvae were laboratory-reared, as were ours, and, therefo
there is no doubt that we and Jørgensen were working with the sa e
species. However, we disagree with Jørgensen that larvae of *M. arena*
may reach 300 μ in length before metamorphosis. His conclusi
regarding the setting size is based not on laboratory-reared *M. arenar*
but on specimens collected in the field and only assumed to be t s

cies. The fact that Jørgensen stated on several occasions that tamorphosis of *M. arenaria* may occur upon attainment of a much aller size than 300 μ strongly supports our opinion. For example, gensen mentioned that in Ringkbing Fjord the size of larvae at tamorphosis in shallow water varies between 200 and 225 μ, thus ng within the size range observed in our cultures.

S. *Teredo navalis* Linné

Larvae of *T. navalis* have been described by many authors, including rgensen (1946), Sullivan (1948) and, also, Imai, Hatanaka and Sato 950), who gave a good description of the method of rearing them.

In our laboratory adult *T. navalis* were conditioned to spawn as rly as the first part of December. This was done by placing pieces of od, containing wood-borers, in sea water maintained at a tempera- re between 15° and 20°C. Spawning occurred at temperatures of °C and higher, and larvae were released at temperatures ranging m about 16° to 20°C. Grave (1928) reported that spawning of . *navalis* began when the water temperature reached 11° to 12°C. nai *et al.* (1950b), however, found that spawning begins when the ater temperature reaches 18°C. Sullivan's (1948) data closely agree ith ours, that spawning and swarming may occur at approximately 5°C.

Although *T. navalis* is naturally larviparous, both recently-rtilized eggs and immature larvae removed from the gill chambers the parents developed normally past metamorphosis. The diameter unfertilized eggs varied between 50 and 60 μ, agreeing with measure- ents given by Jørgensen (1946) and Costello *et al.* (1957). In the issected adults, however, most of the eggs found were either already rtilized or immature, thus presenting difficulty in obtaining reliable gg measurements.

The smallest larvae released in natural swarmings at our laboratory easured only 80 × 70 μ, while the largest larvae found in the gill hamber of the mother were 90 μ long, or approximately 10 μ longer nan reported by Jørgensen (1946). Evidently, the length of larvae t the time of release may vary by at least 20 μ. Imai *et al.* (1950b) ndicated that the mean size at the time of release is 85 × 72 μ. Our bservations that the average size of just-released *Teredo* larvae is etween 85 and 95 μ are in agreement with those of Sullivan (1948), orgensen (1946) and Imai *et al.* (1950a). We cannot, however, accept the onclusion of Lane *et al.* (1954) who maintained that larvae are about 50 μ in size when released from the gill chamber.

Eggs, in early stages of development, taken from the gill chamber of a female *Teredo* were cultured to metamorphosis in 28 days at temperature of about 20°C. Grave (1928) thought that the entire peri of development of *Teredo* from the moment of fertilization to me morphosis takes about 5 weeks. Judging by data offered by Imai *et* (1950a), setting in their cultures occurred between the 24th and 3 days.

A brief description of early stages of development of eggs a larvae of *T. navalis* are given by Costello *et al.* (1957) and of later stag by Sigerfoos (1908). Imai *et al.* (1950b) gave a good account for stages. In our cultures the shells of straight-hinge larvae appear heavy and thick. The larvae were also characterized by a dark ba

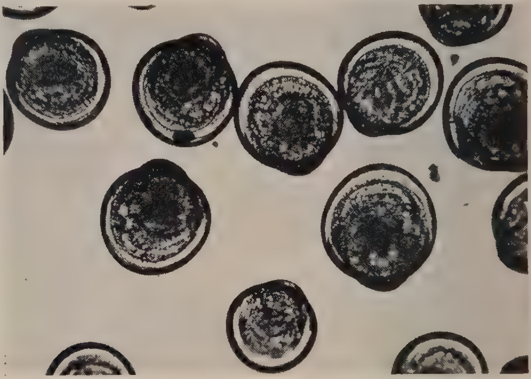


Fig. 43. Late larval stages of *Teredo navalis*. Largest larva in the group is about 18 long and 200 μ wide. Note dark band around edge of shell characteristic of lar of this species.

around the edge of the shell from one end of the hinge to the ot (Fig. 43). A light band was quite conspicuous inside of this dark ba Although these bands are probably optical illusions resulting fr curvature of the shell seen under the microscope, they are well p nounced. The bands are quite narrow and less conspicuous in larv smaller than 90 μ in length but, nevertheless, they are present ev in these small individuals. As larvae approach setting size, the ban become less sharply delineated, although they remain quite promine

The color of larvae begins to darken soon after they reach 100 μ length. Imai *et al.* (1950a) also came to the same conclusion. Howev while Imai reported that neither the foot, otocyst or gill filame appears before larvae reach the size of 200 × 215 μ, we observed th appearance in larvae at least 15 μ smaller.

Imai *et al.* (1950b) gave a table showing growth of *T. navalis* larvae m day to day, indicating length–width relationships during different ges of growth. These data closely resemble ours. Other observations these authors on appearance and behavior of larvae are also in close eement with ours.

Larvae of *T. navalis* are extremely active and usually swim vigor-sly and virtually continuously. This is particularly true of younger ges. We noticed that the larvae have some substance on the outside their shells by means of which they adhere readily to glassware d, as a result, it is extremely difficult to rinse them from beakers, pettes, slides, etc.

Larvae began to metamorphose soon after a length of 200 μ was ached. However, several fully-metamorphosed individuals measuring ly 190 μ in length and 206 μ in width were seen. The largest swim-ing larvae were approximately 200 × 231 μ. Our maximum size of ee-swimming larvae of the wood-borer is, therefore, somewhat naller than the 220 × 250 μ reported by Sullivan (1948), but closely proaches that given by Imai *et al.* (1950).

Larvae of advanced stages do not develop an “ eye ” that is aracteristic of larvae of corresponding stages of other species, such *C. virginica*. The foot of recently set borers is extremely slender nd worm-like. The set attach themselves to the substratum by eans of a byssus.

The time required for larvae in our cultures to reach metamorphosis aried. Early in our work, before good food organisms became avail-ble, the first metamorphosing larvae were observed 20 days after warming, when grown at room temperature. If better growing con-itions were provided, the free-swimming period could undoubtedly e shortened. Nevertheless, we strongly disagree with the conclusions f Lane *et al.* (1954) that the normal free-swimming period of *Teredo* arvae does not exceed 4 days.

Teredo larvae are quite susceptible to fungus diseases. Such nfections were observed on numerous occasions and were probably esponsible for the complete mortalities of *Teredo* larvae in some of ur cultures.

VI. ACKNOWLEDGMENTS

Our studies, which provided most of the material for this article, ave been continuous since 1944 and, naturally, during this time nany people have participated either directly or indirectly. We want o express our appreciation to all biologists of our laboratory, especially to Mr. Paul E. Chanley, who grew larvae of the several species of bivalves discussed in this article ; to Mr. Herbert Hidu, who contribut a great deal of information on utilization of dried algae as larval foo to Miss Phyllis B. Smith, who assisted us in a number of the earli experiments; and to our microbiologists, Dr. Ravenna Ukeles a Dr. Robert R. Guillard, who provided the phytoplankton for o feeding experiments. We are grateful to Dr. F. S. Russell and D Mary Parke of Plymouth Laboratory, England, for sending us inocu of algae, several of which were extensively used in our studies.

We also want to acknowledge the technical help of our Laborato Mechanic, Mr. Joseph F. Lucash, whose ingenuity in designing a building various apparatus for our experiments made possible t successful completion of many of our physiological studies. Mi Rita S. Riccio and Mrs. Florence S. Munz were extremely helpful preparing and editing this manuscript, while to Messrs. Manton Botsfo and Charles Nomejko we are indebted for preparation of the phot graphs and other illustrations.

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EXTRAIT

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ICNAF Spec Pub
1963
North Atlantic Fish
Marking Symposium

34.

Haddock Tag Returns in Relation to Fish Condition

By

JOHN P. McDERMOTT and ROBERT LIVINGSTONE, Jr.*

Introduction

During the past 10 years, more than 15,000 haddock have been tagged in a series of experiments as part of a migration study. Returns, which are now virtually complete, varied from 0.7 to 17.5 percent for individual experiments. A major factor contributing to this wide variability appears to be water temperature. Jensen (this Symposium, No. 30) found that the highest returns were obtained from fish tagged in the spring, at which time water temperature is minimum and the water column is isothermal. Type of tag is another important factor affecting returns, spaghetti tags yielding higher returns than Petersen disc tags (Jensen, contribution No. 30). Still another factor is the physical damage resulting from capture. In this study returns of haddock tagged on one spring cruise were examined in relation to physical condition of the fish at time of tagging.

Materials and Methods

A total of 1,979 haddock were tagged on Georges Bank and Browns Bank in the spring of 1957. The fish were caught with a standard No. 41 otter trawl towed from 20 to 60 minutes in depths from 25 to 60 fathoms. The cod end was opened on deck and the haddock placed in holding tanks of circulating sea water. Haddock that lost their equilibrium were not tagged. Only fish which actively swam in the normal horizontal position were selected for tagging; they were classified as undamaged if no scales were lost and if there was no damage to fins. Damaged fish were placed into one of three categories, corresponding to the following types of damage:

1. Bloody fins only
2. Bloody areas on the body and/or loss of up to 10 percent of scales. (Fish with more than about 10 percent scale loss were not tagged.)
3. Both fin and body damage (1 and 2).

Three tagging methods were used:

1. Petersen disc tags ($^1/_2$-inch diameter) attached with stainless steel pins through the operculum (Rounsefell and Kask, 1945)
2. Petersen disc tags pinned through the flesh of the dorsum
3. Spaghetti tags through the flesh of the dorsum (Wilson, 1953).

The spaghetti tag was a 350-mm length of 2.5 mm (O.D.) yellow, extruded Vinyl tubing with a message and serial number printed on the tubing. The ta was inserted with a needle (described by Fritz, 1959 through the dorsal musculature between the firs and second dorsal fins, and the ends of the tubin were knotted together.

In each haul, method (1) was alternated wit methods (2) and (3) so that approximately twic as many Petersen disc tags on the operculum (922 were used, as Petersen disc tags through the dorsu (572), or spaghetti tags (485). The length frequenc of fish tagged with each method was approximatel the same.

Results

For each tag type, the percentage of returns fro undamaged haddock was higher than returns fro any of the three categories of damaged fish. Spaghett tag returns from damaged fish ranged from 2.4 t 9.7 percent as compared with 17.4 percent retur from undamaged fish (Table 1). Petersen disc ta (operculum) returns from the damaged categorie ranged from 0 to 2.7 percent, as compared wit 5.8 percent from undamaged fish. Correspondin figures for Petersen disc tag (dorsum) returns wer 1.4 to 3.2 percent from damaged fish and 5.6 percen from undamaged fish.

Table 1

Tag returns of undamaged and damaged haddock tagge with spaghetti tags and Petersen discs

	Undamaged	Damaged			
		Fins	Body	Both fins and body	Tota
	Petersen disc (operculum)				
No. tagged ...	670	146	69	37	252
No. returned .	39	2	0	1	3
% returned ..	5.8	1.4	0	2.7	1.2
	Petersen disc (dorsum)				
No. tagged ...	357	63	79	73	215
No. returned .	20	2	2	1	5
% returned ..	5.6	3.2	2.5	1.4	2.3
	Spaghetti tag				
No. tagged ...	305	103	41	36	180
No. returned .	53	10	1	2	13
% returned ..	17.4	9.7	2.4	5.6	7.2

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* U. S. Department of the Interior, Fish and Wildlife Servic Bureau of Commercial Fisheries Biological Laboratory, Woo Hole, Mass., U.S.A.

or each tagging method, returns from all three egories of damage were combined and compared n returns from undamaged fish. χ^2* values were) (Pr = 0.005), 2.71 (Pr = 0.10), and 9.08 = < 0.005) for tagging methods (1), (2), and (3), pectively. Combination of these values ($\chi^2 = 19.79$, egrees of freedom, Pr < 0.005) leaves little doubt t injury associated with damage to fins and body nificantly reduces survival of tagged haddock.

The consistently lower returns from fish with body nage only as compared with returns from fish with damage only suggest that injuries associated with s of scales and lesions on the body may be more ere. However, the data are not conclusive on this nt. Comparison of returns from fish with body mage only and fin damage only (using the same thod described above) gave a χ^2 value of 2.32 which s a probability of about 0.15.

It may be noted that percentage tag returns were gher with spaghetti tags than with Petersen disc gs, which agrees with the result obtained by Jensen o. 30).

Discussion

Beverton, Gulland, and Margetts (1959) found turns from tagged whiting with no loss of scales to three times greater than returns from whiting with vere scale loss. Fin injury and scale loss reduced e percentage of tag returns for yellowtail flounder om 19.7 percent for uninjured fish to 3 percent for jured fish (Royce, Buller and Premetz, 1959). In e present study survival rates appeared to be duced by about one third to one half, depending type of damage.

Loss of scales or mucus and lesions in the skin may rmit improper fluid exchange and invasion of thogenic organisms, and thus contribute to tagging ortality. Fin injury and scale loss may also be sociated with internal injuries.

Summary

Haddock tag returns were examined in relation to physical appearance of fish at time of tagging. Fish selected for tagging were classified either as undamaged or damaged and the latter group was further subdivided into three categories:

1. Bloody fins
2. Bloody areas on body and/or scale loss
3. Both body and fin damage.

Returns from damaged fish (all three categories combined) were significantly lower than returns from undamaged fish, thus indicating that injury associated with fin damage and body damage reduces survival of tagged haddock. Consistently lower returns from fish with body damage only as compared with fish with fin damage only suggest that injuries associated with loss of scales and lesions on the body may be more severe. However, returns from these two categories of damage did not differ significantly.

Spaghetti tags yielded approximately three times as many returns as Petersen disc tags on the operculum or dorsum.

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* Test of homogeneity employing numbers returned and numbers not returned. Single degree of freedom comparisons, adjusted for continuity.

Schmidt & Klaunig, Kiel

CURRENT PROBLEMS IN THE MANAGEMENT OF SCIENTIFIC PERSONNEL

Proceedings of the First Symposium of the

Federal Council for Science and Technology

October 17 - 18, 1963

U. S. Government Printing Office Washington, D. C.

CONFLICT OF INTEREST AND THE FEDERAL SCIENTIST
(Dr. Thomas B. Nolan, Chairman)

Non-official Expression in Writing, Lecturing, and Teaching

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I am going to speak on this subject very briefly, mostly from the point of view of my own Bureau's interpretation of the policies of the Department of the Interior.

It is the policy of the Department to encourage informal non-official expression by our employees on matters within their competence. This, of course, applies to public writings, speeches, lectures, and visual presentations of various kinds. The Department believes very strongly that these activities achieve better understanding of Departmental programs and that it aids in dissemination of the scientific knowledge that our scientists gather in the course of their work.

Other outside activities, like university teaching, are available to our scientists under certain circumstances. There are some restrictions on these activities, but I do not think these restrictions are particularly serious. Of course, if any contribution is made by the Government, either in preparation or in presentation, the employee cannot accept remuneration for such services.

In the Bureau of Commercial Fisheries we accept and encourage these policies. However, we feel we do not have the same freedom to accept compensation or to augment our income as our academic colleagues do. I think there are two principal reasons for this.

One is the possibility of conflict of interest. For instance, I personally have some competence to advise industry and others with respect to pollution of coastal waters. However, it would be very difficult for me to accept such assignments without raising severe problems of conflict of interest.

The other principal reason is that most of our scientists find it necessary to put in much more than their standard 40 hours a week in order to do their job adequately. Consequently, if a man has high principles and a sense of responsibility, there is not much time to accept outside assignments. Thus, it seems to us that, even at today's salaries, many of our people are not compensated adequately for the restrictions upon their freedom that come about because of their regular Government duties.

There are other difficult questions too. All scientists are not competent or willing to undertake such activities, and might not have such opportunity even if they wished to do so. How then do we compensate the scientist who has the ability, and who is losing opportunities because his responsibilities take all his time, or because there are conflicts of interest? How do we do this, yet not overcompensate the people who would not be able to perform such services?

Our general philosophy is that extra-curricular activities of these kinds should be restricted as little as possible at the Departmental or Bureau level. We should stress the ethical aspects of these problems, and the moral obligations of our scientists, and allow our laboratory directors as much freedom as possible to make these decisions. We do not always allow such freedom, but I personally feel very strongly we should give our laboratory directors more freedom than they now have. Abuses will occur, of course, but we think these can be corrected by reasonable supervision.

This question has another aspect, however. I think that as a group, our scientists are not sufficiently aware of the need to communicate the results of their work. Many of them publish a scientific paper or give an address at a scientific meeting and consider that their job is done. I believe that this is just the beginning, that scientists have a real responsibility to communicate their findings in simple, everyday language that the general public can understand. Otherwise, how can the results of our work be put to full use?

For example, the work of our Bureau is done for the benefit of the commercial fishing industry and for the people of the United States as a whole. There are many misconceptions about the causes of fluctuations in the supply of fish, and on the role of fishing and other human activities in producing such fluctuations. How can we put to full use the findings of our scientists with respect to utilization of the living resources of the sea? I believe that by lecturing, by writing popular articles, and by other such activities, we can make important contributions to utilization of the knowledge that we produce and to the welfare of our citizens.

There are many advantages to extra-curricular activities by our scientists. They confer prestige on the individual, on his agency, and on the Government as a whole. In general, such activities broaden the perspective of the individual and improve his performance on the job.

The disadvantages are few, I think, and they are relatively easy to control. There are some dangers of interference with the scientist's regular duties, and this must be avoided, of course. There are questions of conflict of interest, as I have mentioned before.

Writing and lecturing are particularly appropriate outside activities for our scientists. They do not involve large amounts of consecutive time. A man can decide more or less when he is going to undertake such activities, and he can start or stop more or less as he sees fit. Thus, he can carry on such activities in his spare time, in evenings, or at weekends, or at other times that are available to him. There is no serious official restriction in our Department as I see it.

With respect to using information gained as a result of a man's regular duties, there is no serious problem in the Department. We do not do much scientific work of a confidential nature, and we are remarkably free, I think, to make use of information gathered in the course of our regular work. Such activities improve our performance on the job. There is no better way for a man to improve his writing ability than to write. There is no better way to improve his speaking ability than by speaking. So the Government gains; the agency gains; and I think, with respect to writing and lecturing particularly, there is minimum danger of conflict of interest.

So far as teaching is concerned, the same advantages apply. I was pleased to hear Mr. Macy say that the best Government laboratories are those that are associated closely with universities, because I was going to make the same statement with respect to our own Bureau laboratories. While this is not always true, I think it is true as a general statement. Many of our scientists hold faculty appointments when they are closely associated with universities, and many of them carry on such activities without additional compensation. Therefore, they feel justified in taking a certain amount of their working day to prepare and give lectures and to guide the work of students. They compensate for the time lost from their regular duties by putting in extra hours at other times.

We think that teaching has many other advantages. It keeps the scientist up to date. The students that he works with become potential employees if they are impressed with him and his laboratory. The disadvantages are few. A man must spend considerable time in preparation, of course, if he is to give good lectures. This can interfere with his regular duties, but excesses can be avoided and regulated by proper supervision. Therefore, on balance, we believe there is very little doubt that an individual in the Government gains in prestige and in quality of work by such activities.

In summary, I will make just two points. Firstly, limitations on these kinds of extra-curricular activity are imposed chiefly by the pressure of duties and by ethical considerations. There are no serious official restrictions as we see them. Secondly, we do have a problem as to how we compensate scientists who have the ability and the desire to perform such activities, but have limited freedom to do so because their regular duties prevent it. It will be no easy task to provide such scientists with adequate compensation for this lack of freedom without overcompensating those who would not be able to make such contributions.

"Reprinted from the AIBS BULLETIN, Vol. 13, No. 5, 1963, pp. 31-33"

onald L. McKernan and J. L. McHugh

BUREAU OF COMMERCIAL FISHERIES BCF

The Bureau of Commercial Fisheries onducts programs of research, develpment, and services for the commerial fisheries of the nation and the peole of the United States. In 1962, the ommercial fishing industry landed nore than five billion pounds worth 381 million to the primary producer. ost of this harvest came from the sea. he catch sold to the consumer for nore than a billion dollars. Fishing, herefore, is an important U. S. industry.

Total funds available to the Bureau n the current fiscal year are about $32.6 nillion, of which $4.45 million is for onstruction of facilities. Research on he living resources accounts for a najor portion of these funds, about 17.0 million for operation and mainteance and $3.5 million for construction f research facilities. Except for prorams in the Great Lakes and Missisippi River and the fresh-water phases f salmon life history, these funds will e spent for research and exploration on he living resources of the sea. Marine esearch programs are carried out at 19 biological laboratories, 5 exploratory ishing bases, and aboard a fleet of 17 esearch vessels.

Fishery science is a branch of ecolgy, concerned primarily with the rections of natural populations of aninals to increased predation. This prelation is the catching of fish by fishernen, and much research effort by the ureau in the past has been concerned with the effects of fishing on the resource. Early in the history of commercial fishing in the United States, fears were expressed that the fisheries would adversely affect the capacity of the resources to reproduce themselves. It was these fears that led to formation in 1871 of the U. S. Commission of Fish and Fisheries, a forerunner of the Fish and Wildlife Service of the Department of the Interior, of which the Bureau of Commercial Fisheries and the Bureau of Sport Fisheries and Wildlife are a part.

Our scientists have long since learned that fluctuations in abundance of fish stocks are not caused altogether by fishing, nor even by the entirety of manmade changes in the natural environment. They know that abundance often fluctuates from natural causes and that such fluctuations often are confused with the effects of fishing. Funds to study the effects of natural factors have not been easy to obtain. Until recently, industry and the Congress have not been interested in supporting basic research that offered no promise of immediate practical application. Indeed, it has not been uncommon to face hostile questions such as "How much are you spending to study the love life of the tuna?", with the implication that such studies are frivolous. Moreover, the research necessary to understand the complicated interactions and effects of natural factors is much more difficult and costly than conventional fishery research, and, until a few years ago, the Bureau's research budget was extremely modest. The great interest in oceanography recently generated by the Committee on Oceanography of the National Academy of Sciences has helped the Bureau to achieve a better balance in its program with respect to basic biological research. Only with an adequate fund of basic knowledge can we achieve our objectives to reap maximum sustainable yields from the sea's living resources, reduce to a minimum the cost of locating and catching fish, and eventually to improve yields by controlling physical and biological sources of mortality.

To reach such difficult research objectives requires a wide array of disciplines and the very best of brains and qualifications in our research staff. Fishery science includes not only the biology of species of commercial importance but also their interactions with all other life in the waters and with a variety of physical factors. But fishery science does not stop at the boundaries of the ocean, for it is concerned also with man as a predator. Thus, it includes his economics, his laws, his social customs, and his traditions. The fishery scientist must understand all these factors and their interrelationships if he is to succeed. He is the very broadest kind of ecologist. To encourage the best students to make these marine sciences their career, the Bureau has started a program of grants to universities for graduate training.

IG. 1. Aerial view of Woods Hole, Masachusetts. Right foreground: Woods Hole iological Laboratory of the Bureau of Commercial Fisheries. Left of Laboratory: Bureau Aquarium. Background: Marine Biological Laboratory.

FIG. 2. Model of proposed new Bureau of Commercial Fisheries Biological Laboratory, La Jolla, California.

FIG. 3. *Albatross IV*, new Bureau of Commercial Fisheries research vessel based at Woods Hole, Massachusetts.

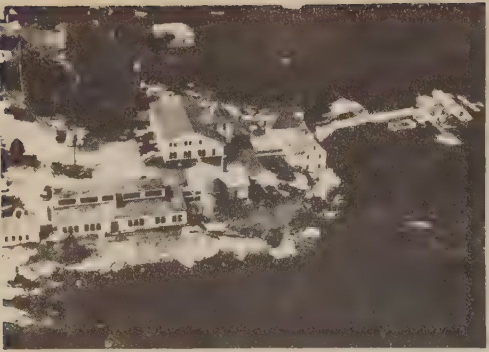


FIG. 4. Aerial view of Bureau of Commercial Fisheries Biological Laboratory at Boothbay Harbor, Maine.

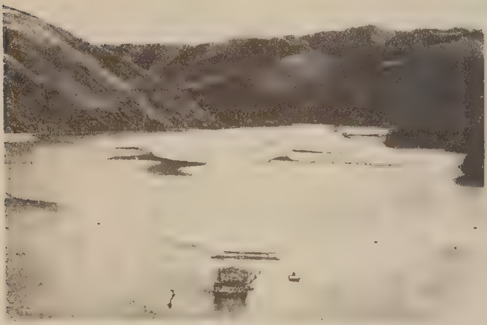


FIG. 5. Experimental trap and leads for collection of young salmon near head of Brownlee Reservoir, middle Snake River area.

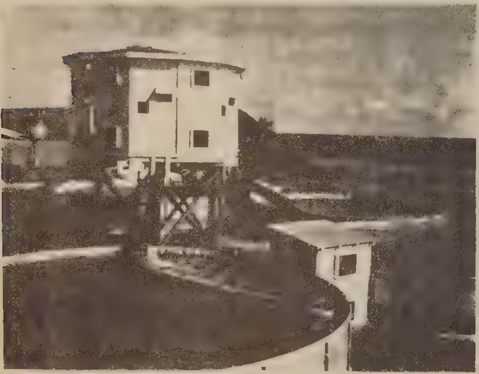


FIG. 6. Tanks in which live tuna are kept for studies of their behavior at the Kewalo Basin shoreside facility of the Bureau of Commercial Fisheries Biological Laboratory at Honolulu. The tower makes it possible to introduce various materials into the tanks and observe the reactions of the fish without revealing the presence of the observers.

FIG. 7. Biologists from Beaufort, North Carolina, Bureau of Commercial Fisheries Biological Laboratory, sampling trapped fish in navigation lock on Cape Fear River, North Carolina, to determine practicability of utilizing the lock for passing anadromous fishes above a dam.

About 40 graduate students are receiving full-time support under this program. The Bureau expects to award an additional 20 grants next year.

In a short paper, it is not possible to describe adequately the variety of exciting research programs under way in the Bureau, nor our plans for the future. The three objectives already cited will require many kinds of research, some of which now are well along and have been signally successful, others of which have barely begun or are yet to be started. To increase substantially the harvest of food from the sea, we must continue conventional analyses of catch and effort of the fishing fleets on a much broader scale than before. We need also to improve our ability to forecast abundance and times and routes of migration. To minimize costs of locating and catching fish, we need to understand the reasons for the characteristic distribution of each species in the ocean and its seasonal and annual changes. We need a much better understanding of migrations and movements, behavior in response to natural and artificial stimuli, and growth and mortality rates. To improve yields by controlling sources of mortality, we need to develop methods of predator and disease control, rearing marine organisms in quantity under controlled conditions, and genetic selection for desirable characteristics such as rapid growth, disease resistance, and good flavor. These objectives are characteristic of the marine biological research programs now being pursued by Bureau scientists in Alaska, Hawaii, and at many locations along the Pacific, Atlantic, and Gulf of Mexico coasts of the United States. A partial list of these challenging and exciting programs now under way follows:

1) Serology and blood chemistry of tunas, salmons, and herring-like fishes.
2) Selection and hybridization of mollusks for desirable characteristics.
3) Behavior of tunas, salmons, and shrimp.
4) Guiding and tracking of marine animals by physical and electronic methods.
5) Diseases of marine animals.
6) Physiology of young sardines.
7) Parasites of herring, shrimp, and salmon.
8) Ecology of estuaries and offshore banks.
9) Spawning and rearing of mollusks under controlled conditions.
10) Control of shellfish predators.
11) Identification and distribution of fish eggs, fish larvae, and invertebrate plankton.
12) Growth and mortality of eggs and larvae of commercially valuable fishes and invertebrates under controlled laboratory conditions.
13) Taxonomy and systematics of marine organisms.
14) Effects of radionuclides on marine animals.
15) Use of radionuclides as research tools in studies of organic productivity, nutrition, and growth.
16) Mapping the living resources of the continental shelves of the United States in time and space.
17) Identification of subpopulations of salmon, sardines, tunas, and many other species by ingenious new techniques such as serology and trace elements.
18) Effects of pesticides on marine organisms.
19) Artificial culture, nutrition, and reproduction of the organism that causes red tide.
20) Large-scale circulation of atmosphere and ocean in relation to fish distribution, migrations, and abundance.

This sampling of current biological research programs gives a general idea of the opportunities for research careers in the Bureau. The variety of environments available for such research ranges from the arctic waters of the Bering Sea to the tropical waters of Hawaii, the Florida Keys, and the tropical Atlantic, and from the shallow, brackish waters of estuaries and salt marshes to the deep ocean. Opportunities for association with foreign scientists are available in connection with Bureau responsibilities for research with international fishery commissions involving more than 20 countries, with various committees of UNESCO and FAO, and at meetings of other international bodies.

UNITED STATES DEPARTMENT OF INTERIOR, THE BUREAU OF COMMERCIAL FISHERIES

DONALD L. MCKERNAN, DIRECTOR
AND THE STAFF OF THE BUREAU

INTRODUCTION

The Bureau conducts a comprehensive program of research, development, and ervices for the commercial fishing industry of the United States. The purpose of hese diverse activities, many of which are carried out cooperatively with industry and with the States, is to strengthen the ishing industry and conserve the resource.

The organization of the Bureau consists of a Headquarters Office in Washington, D. C., five Regional Offices, and two Area Offices. The Headquarters Office includes he Office of the Director and four staff divisions: Administration, Resource Development, Industrial Research, and Biological Research. Field programs are under the supervision and control of Regional Offices in Region 1 at Seattle, Washington; Region 2, St. Petersburg Beach, Florida; Region 3, Gloucester, Massachusetts; Region 4, Ann Arbor, Michigan; and Region 5, Juneau, Alaska. To meet special needs, Area Offices have been established in California at Terminal Island, and in Hawaii at Honolulu.

As the population of the world continues its dramatic increase, many nations are turning to the sea to harvest much-needed supplies of protein food. This has intensified two problems of the United States industry: increasing competition for our coastal resources with the high-seas fleets of other nations, a competition which has raised difficult conservation problems; and a need to increase the efficiency of our own fishing fleets to meet foreign competition. To solve these problems on a friendly yet equitable basis, the Bureau is becoming involved more deeply each year in International Fishery Conventions. We now participate in nine International Fishery Commissions with some 25 to 30 nations, and are active in many other international activities with FAO, UNESCO, and other international organizations. Much of our research is done in close cooperation with other nations, often on the high seas far from our own shores. Basic research is an important part of our international and domestic research programs. Our purpose is to understand the interactions of the resource with its environment, to learn how to harvest fishery resources for maximum sustainable yield, and eventually to farm our natural waters to increase the yield of useful protein.

Scientific studies of the living resource in its environment are carried out at research laboratories on all coasts of the United States, and on the Great Lakes. In Alaska, Hawaii, and on the Atlantic, Pacific, and Gulf of Mexico coasts are 19 Biological Laboratories and 5 Exploratory Fishing and Gear Research Bases. In the Great Lakes area are a Biological Laboratory and an Exploratory Fishing Base. Most of the work of the coastal laboratories forms a part of the Federal Government's National Oceanographic Program. Oceanographic programs include studies of physical and chemical oceanography; biological productivity of the waters; distribution, abundance, and migrations of fishes, crustacea, and mollusks; and identification and ecology of plankton organisms, especially fish, crustacean, and molluscan eggs and larvae. Special work includes studies of diseases of fishes and mollusks, and development of serological techniques to identify fish populations. In the estuarine environment we are learning how to control shellfish predators, and are

Reprinted from AMERICAN ZOOLOGIST
Vol. 3, No. 3, August 1963

studying the effects of pesticides on marine animals. In fresh waters our scientists have developed methods to control the predatory sea lamprey in the Great Lakes; they are investigating spawning and survival of salmon in rivers and lakes; and are developing methods to pass migrating adults and young anadromous fishes safely over dams. Marine mammal investigations include studies of biology and management of fur seals and whales. Investigations of the fisheries themselves are many and varied, concerned with the dynamics of fishery populations and the effects of fishing upon the stocks; yields under different intensities and methods of fishing; and development of techniques for optimum fishing strategy. These are but a few of the Bureau's diverse and complicated investigations of the ecology of fishery populations and the effects of man's activities upon them.

The Bureau publishes more than 300 scientific and technical reports each year. These range from highly specialized scientific papers to popular articles in trade journals and national magazines. Articles on biological research appear in national and foreign scientific journals and in the following publication series of the Department of the Interior: *Fishery Bulletin, Special Scientific Report—Fisheries,* and *Commercial Fisheries Review.*

In support of this program the Bureau is now engaged in a large construction program to replace old laboratories and research and exploratory vessels, and to provide new facilities where needed. Where space is available, visiting scientists will be welcomed at our laboratories and on our ships. Brief summaries of our programs follow.

BIOLOGICAL LABORATORY, SEATTLE, WASHINGTON

Clinton E. Atkinson, Director

Salmon Research

This laboratory is situated on Portage Bay across the Lake Washington Ship Canal from the University of Washington. It shares space with a Technological Laboratory and an Exploratory Fishing and Gear Research Base. Construction of additional laboratory and office facilities is scheduled for 1963-64. The new building will include experimental hatchery and wet-laboratory facilities.

The Biological Laboratory conducts research on salmon in the North Pacific Ocean, the Bering Sea, and in the Columbia River and other fresh waters of the Pacific Northwest. The studies are designed to provide basic knowledge on the life history and environmental requirements of the five species of Pacific salmon. Factors influencing survival and productivity receive special attention.

The International North Pacific Fisheries Convention between Canada, Japan, and the United States designates longitude 175° W as a line separating Asiatic and North American stocks of salmon. The Japanese agreed to abstain from high seas salmon fishing east of this line while scientists sought methods for identifying the continental origin of salmon caught on the high seas and, thus, to determine the distribution and degree of intermingling of salmon of Asian and North American origin.

Research includes studies of (1) the high seas environment and how it affects the distribution of salmon at sea; (2) mortality of salmon at sea; (3) identifying the origin of salmon found at sea by tagging, immunology, morphology; (4) migrations; (5) growth; and (6) physical oceanography.

The laboratory operates the research vessel *George B. Kelez,* a converted U. S. Navy AKL-type ship, 177 feet long.

Salmon research in fresh water is concerned with life histories, times of migration, distribution, behavior, spawning, nursery area requirements, environmental effects, and predator-competitor relationships.

The Columbia River system, which supports valuable commercial and sport fisheries for salmon and steelhead trout, has

GEORGE B. KELEZ

Biological Research Vessel *George B Kelez.* Photograph taken for dedication ceremonies held July 20, 1962, Seattle, Washington.

een modified extensively by dams. More an 70% of original salmon spawning reas have been blocked, and major ecogical changes are taking place. Production of chum salmon in a controlled-flow rtificial spawning channel is under obserbation on Abernathy Creek near Longiew, Washington. Spawning requirements f chinook and silver salmon and the efects of flooding and silting are being studed at a field station at Mill Creek, Caliornia. A field station at Shea Creek on he Yakima River near Ellensburg, Washngton, is set up for salmon predatorompetitor research. A new program to tudy salmon in the estuarine environment is commencing on the Columbia River Estuary.

Special programs include compiling a ompendium of salmon literature and developing techniques for identifying individuals and stocks of salmon by chemical or dietary marking during early life.

Service units provide technical assistance in biometrics, audio-visual presentations, literature research, and translations. Proximity to the College of Fisheries and Fisheries Research Institute at the University of Washington is a decided asset.

Space for visiting scientists is limited at present, but consideration will be given to applications.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, 2725 Montlake Boulevard East, Seattle 2, Washington.

Fish Passage Research

Dr. Gerald B. Collins, Director

The Fish Passage Research Program is devoted to studying the Pacific salmon during its fresh-water life cycle, particularly the effect of the changing environment in the Columbia and Snake Rivers. Originally these salmon migrated up free-flowing streams to spawn. Now they encounter a series of low-head dams and impoundments, increasing water temperatures, pollutants, loss of spawning beds through inundation, impassable dams such as Grand Coulee, and lack of water caused by increasing irrigation demands. When the juveniles migrate to sea, they no longer are afforded the protection of high, rapidly-flowing turbid water from spring runoff. Instead, these waters are now controlled by the series of dams, which not only create areas of clear slack water for easier predation, but also result in an increased mortality rate of the young fish passing over the spillway or through the turbines. The condition now exists in the Columbia River and is planned for the Snake River.

The aim of this laboratory is to apply

knowledge gained from studying changes in migration behavior in those rivers, such as the Columbia, where the environment has been altered, to future river developments. The present research is in cooperation with fishery agencies of Washington, Oregon, Idaho, and California.

Briefly, the program has the following objectives:

1. Effect of impoundments created by dams on fish migration (recruitment, survival, escapement, limnological effects, permanent residence in the impoundment, size, condition and age of fish);

2. collection of downstream migrants from streams and rivers (guiding fish away from areas of high mortality);

3. passage of migrant fish at dams (improving fish passage facilities, new techniques, energy studies, physical limitations of fish, and reducing injury and mortality in spillways and turbines);

4. adaptability of salmon to new environments created by dams (racial behavior and physiology, homing instinct, reaction to temperature and oxygen changes).

Facilities include the headquarters office located at the U. S. Naval Air Station, Seattle, Washington; Fisheries-Engineering Research Laboratory at Bonneville Dam (description in U. S. Fish and Wildlife circular 98); Fish Behavior Laboratory—2725 Montlake Blvd., Seattle (description in Special Scientific Report—Fisheries No. 271); Reservoir Studies, Washington Hotel, Weiser, Idaho; and numerous field stations. Facilities for visiting investigators can be made available at each of the field laboratories and they are, of course, welcome at the Seattle office.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, U. S. Naval Air Station, Building 67, Seattle 15, Washington.

Marine Mammal Research
Ford Wilke, Director

Another Biological Laboratory in Seattle is a center for research on pinnipeds (except walrus) and cetaceans. Its research program aims primarily to conserve an improve management of the Alaska fu seal herd, and to study whales and wha ing. The results, in part, are used by th North Pacific Fur Seal Commission, rep resenting four nations, and by the Inte national Whaling Commission, represen ing 18 nations.

The permanent staff includes eight b ologists, all headquartered in Seattle. A various times, members of the staff carr out research at the field laboratory on S Paul Island, Alaska; at sea on the Nort Pacific Ocean collecting fur seals or mark ing whales; at one of the commercia shore-whaling stations in California; o with Eskimo whaling crews in Arctic Alas ka. In the summers of 1960 and 1961 American biologists visited fur seal breed ing grounds in the USSR while Soviet bi ologists were on the Pribilof Islands, breed ing grounds of the seal herd in Alaska.

The laboratory maintains close workin relationships with the Bureau of Spor Fisheries and Wildlife, especially with biologist specializing in studies of sea otter walrus, polar bear, and marine birds. I also cooperates with various department of the University of Washington and wit the Washington State Museum on the uni versity campus.

The laboratory has facilities for statisti cal analysis (including an IBM key punch); for examining stomachs and re productive tracts; for veterinary research and for anatomical studies of teeth, skulls baleen plates, whale ear-plugs, eye lenses and pelage. It has a library on marine mammals, a reference collection of organisms found in marine mammal stomachs, and a synoptic collection of cetacean parasites. It has no aquarium, public museum, special instruments, or special set-ups. In a sense, its "workshop" is the ocean and adjacent shores.

The St. Paul Island branch laboratory is open from about June to October. Here biologists collect or examine specimens in the fur seal kill, a harvest which includes annually about 60,000 males and 30,000

ales. Fifty thousand seal pups are
ged in September. Extensive collections
data for population dynamics studies
made annually.

By arrangement, and to fill important
entific or educational needs, the biolo-
ts will collect, or help visiting special-
to collect organs, tissues, skeletal parts,
od, entire bodies, and photographs of
rine mammals.

The Seattle laboratory is three miles
rtheast of the University of Washington.
ice the laboratory is on military ground,
itors are asked to obtain an entry pass
the gate, or telephone the Director in
vance. Address the Director, Bureau of
mmercial Fisheries Biological Labora-
y, U. S. Naval Air Station, Building
2, Seattle 15, Washington.

BIOLOGICAL LABORATORIES, BEAUFORT, NORTH CAROLINA

Fishery Research
Fred C. June, Acting Director

Radiobiological Research
Dr. Theodore R. Rice, Director

On a small island, located one-half mile
om Beaufort, North Carolina, stands the
cond oldest Government marine research
ation in the United States. Since its
tablishment in 1899, this Laboratory has
een in continuous operation. Most of the
iginal wooden buildings recently were
placed by brick and concrete block struc-
res, which include a fishery laboratory, a
diobiology laboratory, a small dormitory
r visitors, a residence for the Director, a
nall warehouse, and a maintenance build-
g with wood- and metal-working shops.
Other research facilities include nine
nall outdoor concrete tanks, and two 30
× 40 foot concrete ponds, each supplied
ith running sea water; a 30 × 40 foot
esh-water pond; a 30 × 80 foot tidal
ond; two motor vessels (a 26-foot launch
nd a 50-foot cabin cruiser); and several
iffs equipped with outboard motors.

The diversity of habitats surrounding
he laboratory—the adjacent Atlantic Ocean and nearby navigable inlet; offshore bars; marshes; several large rivers with extensive estuarine areas; and several large sounds of salt and brackish water—provides unusual opportunities for marine research.

The permanent staffs consist of 28 scientists, 8 scientific assistants, 6 administrative and clerical assistants, and 6 maintenance men. Facilities for visiting scientists are available, but limited.

The fishery laboratory provides office space for research and administrative personnel and houses a photographic darkroom, a 4,000-volume library, and a scale-reading room. Facilities for conducting chemical analyses and biological experiments also are provided, and include water tables supplied with running sea water, gas and compressed air outlets, and fume hoods. Scientific studies, directed toward the solution of basic biological and fishery problems, are divided into three programs. These are concerned with determining the cause and predictability of variations in abundance of blue crabs, menhaden, shad, and striped bass; problems of fish passage over dams; and estuarine and coastal hydrographic studies.

The radiobiology laboratory, located in a separate building, includes a counting room, an algal-culture room, an experimental-aquarium room, and two constant temperature rooms. Also there are separate rooms for chemical analyses and physiological experiments. The work, sponsored in part through a cooperative agreement with the Atomic Energy Commission, is concerned with accumulation and retention of radionuclides by marine organisms and sediments; application of radioisotopic methods to studies of estuarine ecology and pond culture; and determination of the effects of radiation on marine organisms.

Summer visitors to the laboratories may reach Beaufort by air. During the remainder of the year there are regularly-scheduled flights to New Bern, North Carolina, and bus transportation is available from

New Bern to Beaufort. Dormitory facilities for three or four persons are available for official visitors. Requests should be placed in advance with one of the laboratory directors. Address the Acting Director, Bureau of Commercial Fisheries Biological Laboratory (Fishery Research), Pivers Island, Beaufort, North Carolina, or the Director, Bureau of Commercial Fisheries Biological Laboratory (Radiobiological Laboratory), Pivers Island, North Carolina.

Bureau of Commercial Fisheries, Biological Laboratories, Beaufort, North Carolina (Radiobiological Laboratory is on the waterfront, right foreground)

BIOLOGICAL LABORATORY, BRUNSWICK, GEORGIA

William W. Anderson, Director

This Laboratory is engaged in studies of ocean waters adjacent to the coast of the United States from Cape Hatteras, North Carolina, to the Florida Straits. Included is a biological inventory to determine the presence, identity, distribution, and interrelationships of marine forms of the area. Special attention and effort are directed to fish larvae and juveniles, life histories of important species, and systematics of selected groups of fishes in the western North Atlantic Ocean. More limited efforts are directed to the biochemistry of the waters to establish distribution and concentrations of nutrients, trends in temperatures and salinities, and composition of bottom sediments.

Coastal Georgia is characterized by a series of heavily wooded offshore barrier islands, numerous passageways between the islands, large sounds, and a 10- to 15-mile-wide, rich, marshy estuarine area between the islands and the mainland. This marsh area is cut with numerous salt water rivers, creeks, and guts. Normal tidal rise and fall is approximately six feet, but in the fall this may reach 10 to 11 feet. Five fresh-water rivers enter the ocean in Georgia's 90 miles of coast—the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys.

The fauna is typical of the South Atlantic coast of the United States. The dominant fish group is the croaker family *(Sciaenidae)* and the most abundant large

Federal Building, Brunswick, Georgia, U. S. Bureau of Commercial Fisheries Biological Laboratory occupies one-half the top floor.

crustaceans are shrimp *(Penaeus)* and crabs *Callinectes)*.

The Laboratory occupies approximately one-half the top floor of the Federal Building in Brunswick, Georgia. In addition to standard chemical and biological laboratory facilities there are photographic and darkroom space and equipment, X-ray equipment, drafting room, library, and an excellent reference collection of fishes from the general study area and from the Gulf of Mexico and the Caribbean. There is no running sea-water system.

Working space and equipment can be provided for one or two visitors for short periods. There are no living accommodations at the Laboratory, but reasonably-priced hotels and restaurants are available nearby. The Federal Building is located on Gloucester Street in Brunswick.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, P. O. Box 280, Brunswick, Georgia.

BIOLOGICAL LABORATORY, GULF BREEZE, FLORIDA

Dr. Philip N. Butler, Director

The Laboratory consists of nine buildings with approximately 5,000 square feet of working space devoted to offices, dry laboratory rooms, and administration; 1,000 square feet of wet laboratory rooms; and 2,000 square feet for storage and shop facilities. A permanent staff of 15 (2 Ph.D.; 5 M.S.), including the Resident Director, is conducting a research program devoted primarily to estuarine ecology. Special emphasis is placed on studies of cyclic changes in animal populations, the biology of commercial shellfish, and the effects of pollution due to agricultural chemicals.

The Laboratory is located on a 15-acre ballast rock island in the center of a complex of shallow communicating bays, a sound, and the Gulf of Mexico. Several small rivers entering the area have a 4,000 square mile drainage basin. Habitats vary from fresh-water rivers to the open Gulf with a salinity approximately $32^{0}/_{00}$. Fresh- and salt-water marshes are extensive and less than half of the shore line is developed. The bottoms are predominantly clean hard sand with mud only in the deeper channels. The fauna is extremely diverse, and relatively few species are found in abundance.

Standard laboratory equipment is available, including fluorometer, spectrophotometer, and facilities for Carbon-14 studies. There is a photographic darkroom and a well-equipped shop. The wet laboratory has a continuously flowing, plastic-pipe water system with a gravity flow of sea water to 120 linear feet of concrete water tables. A 36-foot diesel-powered work boat is equipped for trawling and dredging. There are several outboard-powered smaller collecting boats.

Sea-water salinity fluctuates with the single daily tide and typically ranges from the spring lows of $15\text{-}20^{0}/_{00}$ to $25\text{-}28^{0}/_{00}$ in late fall and winter. Water temperatures range from 10° to 30°C. Average summer and winter air temperatures are 27° and 13°C respectively. Temperatures below 0°C rarely occur.

A limited amount of research space is available (no fees) to qualified workers as well as dormitory facilities (nominal charge) for men. Applications for space should be made well in advance of the time desired.

Nearby Pensacola Beach is a typical summer vacation area with expensive housing facilities in season. Pensacola, serving a metropolitan area with a population of 75,000, is 12 miles north and has ample residential and shopping facilities. Pens cola airport (EAL, NAL) is 15 miles fro the laboratory.

Address the Director, Bureau of Con mercial Fisheries Biological Laborator Gulf Breeze, Florida.

reau of Commercial Fish
water laboratory

Bureau of Commercial Fisheries Biological Laboratory, Gulf Breeze, Florida

BIOLOGICAL LABORATORY, GALVESTON, TEXAS

Milton J. Lindner, Director

The Laboratory is on the Gulf of Mexico, and in a residential area of Galveston (population 71,000). A large sea-water station four miles from the main laboratory is built over an estuarine lagoon. Hotel and motel accommodations in Galveston are excellent and reasonably priced. The climate is suited to year-round field activity.

Facilities include a fully-equipped cher istry laboratory, large controlled-temper ture rooms, recirculating and constant flo sea-water systems, culture rooms, physi logical apparatus, a good marine librar a 40-foot diesel vessel and smaller boa for estuarine work, and modern ocean graphic apparatus for field sampling. O shore work on the continental shelf fro Brownsville to the Mississippi River is co ducted from larger chartered vessels.

The research program is concerned wi the life history and dynamics of seve

Bureau of Commercial Fisheries, Biological Laboratory, Galveston, Texas

cies of shrimp, physiology and behavior shrimp and local estuarine fishes; ecol- , distribution, life histories and abund- e of estuarine species; oceanography of continental shelf as it affects the fauna, luding hydrographic and biological as- ts; methods for controlling blooms of rine protozoa; chemistry of sea-water; related problems that may bear on the ve research. Quantitative biology is ssed.

rrangements for a limited number of ting investigators in marine biology or anography may be made. By air, one lanes at Houston and travels 50 miles limousine to the Laboratory. Galveston lso served by major railway and bus npanies.

ddress the Director, Bureau of Com- rcial Fisheries Biological Laboratory, t Crockett, Galveston, Texas.

field station was established at St. ersburg Beach to conduct research on Florida red tide. A two-story building a dock-side garage incorporate some 7,000 square feet of space for biological and chemical laboratories, library, conference room, offices and storage. In January 1962, funds were appropriated for research on estuaries in the eastern portion of the Gulf of Mexico. The research program, no longer associated with red tide, became known as East Gulf Estuarine Investigations. The chief objectives are to study the ecology of estuarine organisms and the effects of urbanization, industrialization, and engineering upon resident biota. The research program is largely fundamental and is designed to include the following projects: Hydrology-Plankton, Chemical Environment, Faunal Production, Circulation Dynamics, Benthic Communities, and Engineering Effects. The staff consists of nine scientists, clerk-stenographers, a librarian and a vessel captain.

The center of investigation is Tampa Bay, one of the largest and most productive estuaries connected with the Gulf of Mexico. Visiting investigators can make arrangements by writing the Director, Region 2, Bureau of Commercial Fisheries, St. Petersburg Beach, Florida.

BIOLOGICAL LABORATORY,

BOOTHBAY HARBOR, MAINE

Bernard E. Skud, Director

This is the largest year-round marine laboratory on the United States coast of the Gulf of Maine. The original facility was established in 1905 as a hatchery for lobsters and groundfishes. Hatchery efforts were abandoned in the 1940's, and various marine research projects were substituted. Several recent additions and renovations have expanded the research facilities.

The staff numbers 35 employees: 15 biologists, 10 technicians, and 10 in various supporting services. Research efforts are divided into two major components. The larger is the Herring Program, concerned with the biology of *Clupea harengus* and its utilization in the Maine sardine industry. The other is the Clam Program concerned with the soft-shell clam, *Mya arenaria,* and the surf clam, *Spisula solidissima.* Herring research includes studies of age and growth, abundance and availability, biostatistics, diseases, migration, behavior, and serology. Clam research includes studies of environmental requirements, laboratory rearing, feeding, reproductive cycles, basic physiology and various population parameters.

The Laboratory, centrally located in the Gulf of Maine, affords the opportunity of studying estuarine and marine habitats. The fauna is rich and varied. Herring are the dominant pelagic species, but many other fishes, such as mackerel, are abundant, and larger species of shark and tuna are also available. Groundfish populations are varied and plentiful. The numerous shellfish stocks include clams, scallops, mussels, and oysters — the American and the introduced European species. There are extensive fisheries for lobsters and marine worms. Other bottom invertebrates such as starfish and sea urchins abound.

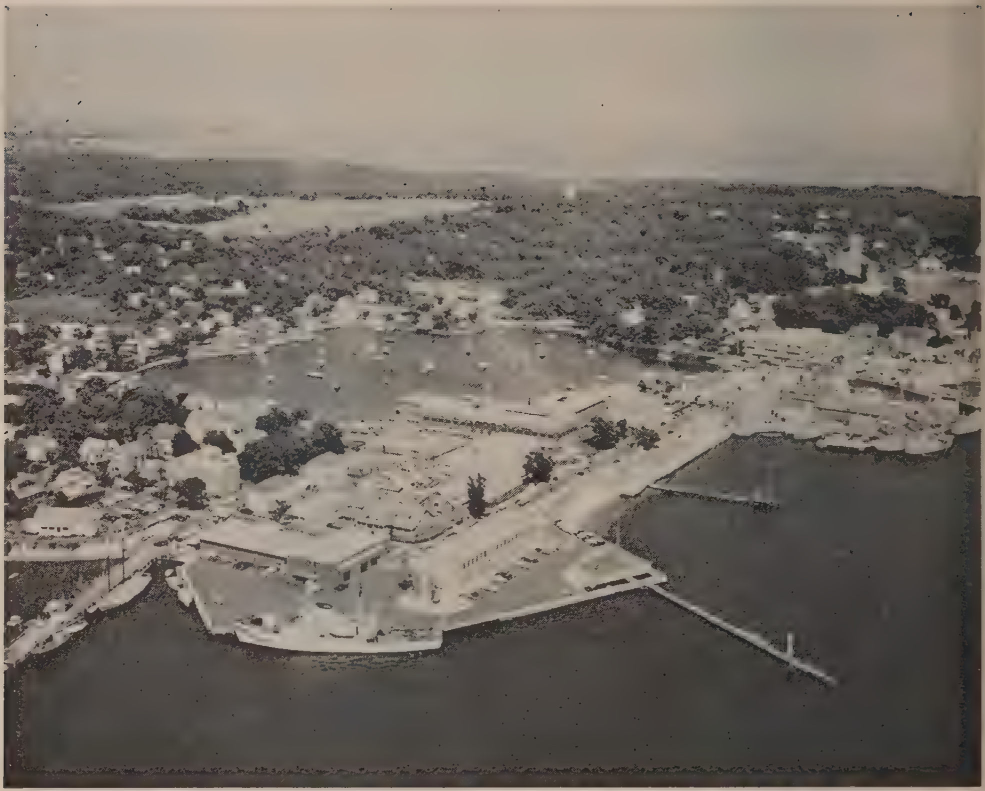
The research facilities of the Laborator include a sea-water system which provide over 200 gallons per minute. There is an array of tanks and water tables of variou sizes and shapes for experimental work A recent addition to this system include a controlled temperature and salinity unit delivering 100 gallons of water per hou at temperatures from 0°C to 30°C and salinities from fresh to 30 $^0/_{00}$. The dr and wet laboratories contain a refrigerate centrifuge, tissuematon, electrophoresis apparatus, and other experimental equipment. A modern photographic darkroo provides wide flexibility for experimenta studies as well as for publication need Drafting services are also available at th Laboratory. Vessels are limited to a 40-foo research vessel, *Phalarope II,* and severa smaller outboard craft. The wharf facil ties are excellent, and deepwater ancho age is available for large sea-going vessel

The Maine Department of Sea and Sho Fisheries operates a marine aquarium o the Federal property, and conducts a r search and management program on lo sters and clams.

Space for visiting scientists in the la oratory is available, but limited to two o three individuals. Housing can be o tained readily in the local community.

No public transportation serves Boot bay Harbor, thus automobile transport tion is necessary. Commercial airlines fro Boston serve Portland, Maine. Arrang ments can be made to transport visito to the Laboratory — a distance of 50 mil

Address the Director, Bureau of Co mercial Fisheries Biological Laborato Boothbay Harbor, Maine.



The Woods Hole Laboratories, Photograph by C. Spooner, July 5, 1963.

The village of Woods Hole in the town of Falmouth, Massachusetts, is the site of three well known institutions — often confused with one another. Although there is a separate article for each it seemed likely that a view of the group would be useful. Also the author-editor shares with many other zoologists both American and otherwise a prejudice for the biological traditions of Woods Hole. Mr. C. Spooner, photographer of the Woods Hole Oceanographic Institution, made a special effort to obtain this photograph for use here.

The Bureau of Commercial Fisheries, Biological Laboratory is the oldest (1875) and it is under the authority of the Fish and Wildlife Service in the United States Department of the Interior. It is still locally referred to by its earlier names: "Fish Commission," "Bureau of Fisheries," or "The Fisheries." Its two new major buildings, replacing the original ones, are in the foreground of the picture surrounded by parking areas and extensive dock space. The new fisheries-oceanographic research vessel, *Albatross IV,* is at the dock. The major office building and laboratory is to the right, to the left is a shop and the Aquarium. The Aquarium is open to the public only in the summer and is used for research in other seasons.

The Marine Biological Laboratory, incorporated in 1888, is a self-governing institution whose primary functions are to make adequate facilities available to professional biologists for investigations requiring marine animals and other special facilities, and to provide instruction for students. In the picture, above the Bureau of Commercial Fisheries building is a block which includes the newest research laboratory, facing the harbor, to its left the Old Main (original) building, and other frame buildings for teaching, research, and living and dining quarters. Across the street, in the center of the photograph, is the main laboratory building, and several accessory buildings.

The Woods Hole Oceanographic Institution is a self-governing corporation, the youngest (1930) and largest of the three. It conducts an extensive year-round program in all aspects of oceanography. Much of its current work is in cooperation with the United States Office of Naval Research. At the right of the photograph are its docks and dock facilities and two large research buildings. Farther up and across the street is its new (1963) research building. Additional storage and work areas are nearly concealed by trees. Research Vessels *Atlantis, Gosnold,* and *Crawford* are at the dock. *RV Chain* and *RV Atlantis II* are not shown.

ALBATROSS IV
WOODS HOLE

Albatross IV, commissioned 1962

BIOLOGICAL LABORATORY,

WOODS HOLE, MASSACHUSETTS*

(Shown in frontispiece.)

Dr. Herbert W. Graham, Director

The program of the Bureau of Commercial Fisheries Biological Laboratory at Woods Hole is concerned with research on the offshore commercial groundfish of the Northwest Atlantic: their life histories, ecology, and conservation. Principal species under study are cod, haddock, silver hake, redfish, flounder, and sea scallop. Particular emphasis is placed on the study of population changes in these and associated species of groundfish. These studies involve assessment of the effects of fishing upon the various stocks and the effects of the environment. As part of the environmental studies, the Laboratory has a broad program of studies of benthic fauna, plankton, and hydrography. The areas of interest include the Gulf of Maine and Georges Bank, a portion of the Atlantic Coastal Shelf with highly productive fishing banks.

The laboratory staff consists of 25 professional scientists and a supporting staff of 40 which includes subprofessional scientific personnel, administrative staff, and maintenance personnel.

Physical facilities include two buildings, two research vessels, and a deepwater dock. The laboratory building is a three-story structure with 24,000 square feet of floor space, 33 research rooms, large tank room, conference room, library, administrative offices, and walk-in refrigerators. The first floor rooms are supplied with running salt water. The second building houses a public aquarium of 16 tanks in which local species of fishes are exhibited, an experimental tank area, and maintenance shops. The seawater in this building is filtered and temperature controlled.

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* The history of this laboratory is described in Galtsoff, P. S., 1962, The Story of the Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts. U. S. Dept. of Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries, Circular 145, Washington, D.C.

The *Albatross IV,* based at the Laboratory, is a 1,000-ton modern fishery-oceanographic research vessel with accommodations for 16 scientists. It is equipped for all kinds of oceanographic and groundfish research and makes regular cruises to the area of interest, each cruise lasting about two weeks. The *Blueback* is a 40-foot motor vessel used for inshore collecting.

The Laboratory is operated on a year round basis and no special accommodations are provided for summer investigators. Scientists working on problems related to the laboratory program are welcome to use facilities when these can be made available. They may also participate in the cruises of the *Albatross IV,* but diversion of the vessel from its regular schedule usually cannot be made.

Living accommodations are available in Woods Hole and in the nearby town of Falmouth, although rates are very high during the tourist season which extends from about the 15th of June to the 1st of September. Woods Hole is two hours from Boston, Massachusetts, by bus or car.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts.

BIOLOGICAL LABORATORY,

MILFORD, CONNECTICUT

Dr. James E. Hanks, Director

Naturally-occurring populations of oysters and clams have supported fisheries in Long Island Sound for centuries. The Eastern oyster, *Crassostrea virginica,* and the hard clam, *Mercenaria mercenaria,* are the major species. Some softshell clams, *Mya arenaria,* and black mussels, *Mytilus edulis,* are harvested by local shellfishermen.

The first permanent assignment of a full-time biologist and establishment of a laboratory were in November, 1931. This small program was concerned with biological problems facing the Connecticut shellfish industry. Construction of the present laboratory building was completed in 1940.

Bureau of Commercial Fisheries Biological Laboratory, Milford, Connecticut

The Laboratory has made significant contributions to the knowledge of temperature, salinity, and turbidity tolerances of adult oysters; and of gametogenesis, spawning, and metamorphosis of these and other pelecypod mollusks. Studies of environmental requirements and tolerances of bivalve larvae have reached a point where establishment of commercial hatcheries seems feasible. Considerable progress has also been made in developing methods for control of the various predators and competitors of shellfish.

The Laboratory has facilities for all phases of research in marine biology. Warm and cold running sea water is piped to a number of water tables and can be provided throughout the building for experiments in trays or aquaria. Large outdoor tanks are also available, with either tidally exchanged or continuously-pumped sea water, for experimental or storage use.

Supplemental algal food, suitable for most filter-feeding invertebrates, is pumped to the research rooms from a 2,000-gallon culture tank. In addition, a collection of approximately 80 species of marine algae is maintained in bacteria-free culture. Several of these are reared, using continuous culture techniques, so that as much as 48 liters per day of unialgal, bacteria-free algal suspension are available for experimental work.

Workshop facilities are located on the grounds, and experienced personnel can construct most types of specialized laboratory equipment on order.

The laboratory's 50-foot research vessel operates on a year-round basis in Long Island Sound. It is outfitted with standard hydrographic gear, in addition to dredge equipment for sampling benthic organisms. The vessel has a 10- × 14-foot research laboratory on the main deck, supplied with A.C. and D.C. current, which can accommodate a complement of four to six scientists. Several smaller outboard-powered boats are available for inshore work. The laboratory has standard SCUBA equipment including an air compressor unit, and there is a trained diver/biologist on the staff.

A limited library of reference and reprint material is maintained at the Laboratory. Complete library facilities are available through Yale University and the Bingham Oceanographic Laboratory at New Haven, Connecticut, only a few miles away.

The research program has three objectives: (1) basic studies of the physiology and ecology of larval and adult pelecypod and gastropod mollusks, in particular in the Eastern oyster, *Crassostrea virginica,* hard clam, *Mercenaria mercenaria,* and oyster drills, *Urosalpinx cinerea* and *Eupleura caudata*; (2) development of techniques to improve the culture of commercial shellfish under controlled and natural conditions; and (3) development of methods for mechanical and chemical control of shellfish predators.

The staff consists of eight fishery biologists; two microbiologists; and supporting administrative, maintenance, and clerical personnel.

The Laboratory is located on Milford Harbor in a distinctly estuarine environment. Within a modest distance are salt-marsh areas, natural salt-water ponds, a number of tidal estuaries, and various benthic conditions in Long Island Sound from soft mud to sand and rock bottoms. Although large sections of the local inshore waters are devoted to oyster production, many natural areas exist where benthic marine communities and predator-prey ecology can be studied. Salinities range from 27-30 $^{0}/_{00}$ in the open Sound to 10-12 $^{0}/_{00}$ in areas of river discharge.

Facilities are available at no charge throughout the year for one or two visiting investigators. Living accommodations are not available at the Laboratory, but convenient room rental arrangements can be made locally. Requests for the use of facilities and an outline of the research program contemplated must be submitted three months in advance of desired occupancy.

The Laboratory can be reached by airline, train, or bus service to Bridgeport and New Haven, Connecticut.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, Milford, Connecticut.

BIOLOGICAL LABORATORY, OXFORD, MARYLAND

James B. Engle, Director

Marine biological research in Chesapeake Bay by the Bureau of Commercial Fisheries and predecessor agencies dates back almost 100 years. Present investigations, concerned directly with shellfish biology, ecology, and culture, began in 1944. Since 1960 the work has been based at newly constructed facilities near Oxford, Maryland. Early investigations were short-term intermittent observations on unusual mortalities, and were efforts to demonstrate systems of culture such as methods of seed production, transplantation, and feeding of oysters. The present program includes basic marine biology and ecology; survival, growth, and condition; and methods of culture and management. Close liaison is maintained with State research and management agencies and the shellfish industries.

The principal early efforts of the investi-

Bureau of Commercial Fisheries Biological Laboratory, Oxford, Maryland

gations included ecological and biological surveys, precise area population studies, and general hydrographical observations. More recently, studies of factors affecting reproduction, growth, survival, recruitment, and genetics were added to the program of research. Strong emphasis is given to research on problems of shellfish mortalities, including identification, life histories, control of predators, micropathogens, and the effects of environmental changes.

There are other mollusks and crustaceans of commercial significance in this area. In Chesapeake Bay the soft clam *Mya arenaria,* the hard clam *Mercenaria mercenaria,* and the blue crab *Callinectes sapidus,* are harvested commercially in considerable quantity.

The Laboratory is located on a typical estuary with a salinity range from fresh to oceanic water. It is an excellent breeding, nursery, and feeding ground for many sport and commercially important fishes. In the ocean adjacent to this area and in seaside bays, are surf clams (*Spisula solidissima*), hard clams, crabs, and many fish species of recreational and commercial importance.

Floor space of 10,000 square feet includes laboratory facilities for chemical, microbiological, and physiological research. Running sea water is available in some rooms. A limited amount of space is available for visiting investigators. Living accommodations are available in the town of Oxford within walking distance of the Laboratory, which is situated on the Tred Avon River one mile south of the town.

Oxford is 10 miles west of Easton, Maryland. Interstate buses connect Easton with all sections of the country. Baltimore, Maryland, and Washington, D. C. are the nearest rail and air terminals, and Easton can be reached by bus from both cities

The staff is composed of 12 professional scientists and an equal number of supporting aids and technicians.

A small substation (3,000 square feet of floor space), located on a seaside bay, Chincoteague, at Franklin City, Virginia, contains most of the facilities listed for the Oxford Laboratory. The salinity is oceanic (32 ‰) most of the time. There are no accommodations for extended research by visiting investigators, although scientists are invited to use the laboratory as a starting place for field collection trips. It is isolated and not accessible by public carrier.

Boats equipped for general hydrographical and biological sampling are assigned to each laboratory.

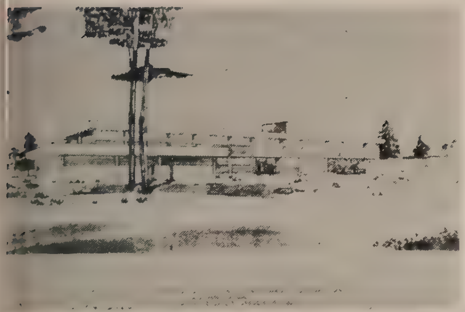
Address the Director, Bureau of Commercial Fisheries Biological Laboratory, P. O. Box 278, Oxford, Maryland.

BIOLOGICAL LABORATORY,

ANN ARBOR, MICHIGAN

Dr. James W. Moffett, Director

This laboratory, located about 40 mile west of Detroit, near the intersection o highways I-94 and US-23, can be reached by bus, railroad, or via commercial airline to Detroit Willow Run or Metropolitan airports. Field biological stations are located in Wisconsin at Ashland; in Ohio at Sandusky; and in Michigan at Ludington Marquette, Millersburg, and Northville Field activities are supported by three research vessels, 45 to 60 feet long — th motor vessels *Cisco, Siscowet,* and *Musk II.*



rchitect's sketch of Bureau of Commercial Fish- ies Research Laboratory, Ann Arbor, Michigan

The Great Lakes have a connected water ea of 95,170 square miles. Each lake ratifies thermally and has at least partial e cover in winter. Other physical, chem- al, and biological characteristics vary idely among the five lakes and to a large tent within each of them. The deepest d largest, Lake Superior, has an average epth of 487 feet (maximum, 1,333); an ea of 31,820 square miles; average maxi- um surface water temperature, 66°F; dis- lved solids, 60 p.p.m.; and an annual mmercial fish production of less than 1 ound per acre. Corresponding data for ake Erie, the shallowest, are: average epth, 58 feet (maximum 210); area, 9,930 uare miles; average maximum surface ater temperature, 78°F; dissolved solids bout 200 p.p.m.; and average fish pro- uction about 7 pounds per acre. Fishes roduced in the Great Lakes are primarily om the genera *Coregonus, Perca, Stizos- dion, Salvelinus,* and in recent years, *smerus*; total commercial production U. S. and Canada) is seldom less than 00,000,000 pounds per year.

Federal research in fisheries and limnol- gy on the Great Lakes has been continu- us since establishment of the laboratory 1927. Since its inception, the work has een carried out in close cooperation with he University of Michigan, and the facil- y's headquarters have been on the Uni- ersity campus. The original small staff as increased to a current full-time comple- ent of 90, of whom 50 are fishery biolo- ists.

The laboratory's biological research is directed primarily toward development of a basic understanding of Great Lakes fish stocks — the life history, ecology, and interrelations of different species; factors of fluctuations in growth and abundance; and the effects of the environment and of varying rates of exploitation. Since 1949, a major portion of the effort has been concerned with studies of the effects of predation by the sea lamprey, *Petromyzon marinus,* on fishes in Lakes Superior, Huron, and Michigan; the development of methods for its control; the experimental application of control methods; and the rehabilitation of stocks of lake trout, *Salvelinus namaycush,* which the sea lamprey brought to commercial extinction. A second major field of study has been the relation of recent pronounced changes in the limnology of certain waters and the accompanying major shifts of species abundance.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, 1220 East Washington Street, P. O. Box 640, Ann Arbor, Michigan.

BIOLOGICAL LABORATORY, AUKE BAY, ALASKA

Dr. George Y. Harry, Director

This laboratory serves as research headquarters for the Bureau in Alaska. It is located in Southeastern Alaska 12 miles north of Juneau, the State Capital. Completed in 1960, the two-story building houses facilities for controlled experiments relating to the biology and physiology of fish and shellfish in fresh and salt water. Nearby Auke Lake and Mendenhall Lake serve as natural fresh-water experimental areas, while adjacent Auke Bay is used for estuarine studies.

The Laboratory also houses a growing reference collection of over 300 species of fresh- and salt-water fishes and shellfishes native to Alaskan waters. Other facilities include a comprehensive scientific library,

Bureau of Commercial Fisheries Biological Laboratory, Auke Bay, Alaska

a complete water chemistry laboratory, photographic dark room, and statistical section with IBM card processing equipment. The building also contains office and laboratory space for about 30 scientists and 12 supporting personnel. In addition, the Bureau maintains an 86-foot power barge fitted out for oceanographic investigations now being conducted throughout Southeastern Alaska waters by laboratory personnel.

Other investigations currently under way include studies of the physical, chemical, and biological factors affecting the fresh-water and early marine survival of Pacific salmon, studies of the population dynamics and biology of the commercially important shrimp species and king crab in Alaska, and a study of the effects of DDT application as a forest insecticide on salmo survival in southeastern Alaskan streams.

The area adjacent to the laboratory includes a variety of ecological situations i terrestrial and aquatic environments. Alpine tundra, Sitka spruce rain forests, glacial out-wash plains, glaciers, and permanent snow fields all lie within easy acces from the laboratory. Clear and glacia lakes, ponds, short coastal streams an rivers provide a variety of fresh-water environments for study. The many estuarie islands, and miles of beaches afford numerous opportunities for those wishing t study intertidal and marine environment

Visiting investigators are welcome. Laboratory facilities usually are available fro June to the end of August, a time whe many resident biologists conduct thei studies at various field stations located throughout the State. Living accommodations may be obtained either in Juneau or in the smaller communities of Douglas or Auke Bay. Reservations for housing should be made well in advance of the proposed field season. Often arrangements can be made through the laboratory staff to rent from resident biologists spending the summer at outlying field stations. Investigators considering southeastern Alaska as a study area should include at least 25% addition to their cost-of-living budget over other regions of the United States.

Juneau can be reached by air or water but not directly by car. Several commercial airlines and a state-operated marine highway system provide regularly scheduled service. Ferries with automobile facilities connect with the Alcan Highway at Haines, and there is ferry service from Prince Rupert.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, P. O. Box 1155, Auke Bay, Alaska.

BIOLOGICAL LABORATORY,

STANFORD, CALIFORNIA

Dr. O. E. Sette, Director

This laboratory is engaged in the study of ocean-wide, medium-term changes in the oceanographic conditions in the Pacific Ocean, the processes that cause them, and the effects they have on the abundance of Pacific marine fish populations. The Laboratory uses published and unpublished time-series data on the atmosphere, ocean, and fisheries. It does not engage in collection of data, but is assembling an extensive "library" of published and unpublished data of this description.

The Laboratory is located in the School of Biological Sciences on the Stanford University campus. No space is available for visiting scientists.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, 450 B Jordan Hall, Stanford, California.

Bureau of Commercial Fisheries Biological Laboratory, La Jolla, California

BIOLOGICAL LABORATORY,

LA JOLLA, CALIFORNIA

Dr. Elbert H. Ahlstrom, Director

This laboratory at present is housed in a two-story white frame house on the campus of the University of California at San Diego, Scripps Institution of Oceanography. A new modern laboratory for which plans are almost completed should be ready for occupancy in early 1964.

The San Diego area has become one of the leading fishery research centers in the United States. Within easy commuting distance of each other are two laboratories of the Bureau of Commercial Fisheries, the Inter-American Tropical Tuna Commission, Scripps Tuna Oceanography Research, and the Marine Life Research Program of the Scripps Institution of Oceanography. All except the last-named will be housed in the new laboratory. In addition, the new building will provide generous facilities for visiting scientists interested in studying marine life.

The Laboratory is investigating population dynamics of pelagic fishes, particularly the Pacific sardine and ecologically associated species including northern anchovy, Pacific mackerel, and jack mackerel. Research on the sardine and related species forms part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI).

In its investigation of the habitat of pelagic fishes in the area of the California Current system, the laboratory operates a 133-foot research vessel, the *Black Douglas*. Cruises, varying in length from a day to a month, are made off the coasts of California and Baja California, Mexico.

Particular emphasis has been placed on investigation of factors underlying success or failure of year broods of pelagic marine fishes. Another problem being given increased attention is the interactions of fishes within the same trophic level — particularly the interaction of Pacific sardine and northern anchovy populations. As one result of the bio-oceanographic cruises, this laboratory has accumulated one of the more extensive collections of larval marine fishes in the world. Most of these have been identified.

The Laboratory is situated on the southern California coast about 15 miles from San Diego and 35 miles from the Mexican border, easily accessible by auto, bus, train and plane. A variety of housing is available. The climate is classified as Mediterranean with mild summers and mild winters. The average temperature is 65°F. Rainfall averages about 9 or 10 inches a year, most of which falls in winter.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, P. O. Box 271, La Jolla, California.

BIOLOGICAL LABORATORY,

SAN DIEGO, CALIFORNIA

Gerald V. Howard, Director

The Bureau established this laboratory in 1959 as its center for oceanographic and biological research on the tunas of the eastern Pacific Ocean and for studies of tuna fishing operations. The primary function is to apply oceanographic and biological findings to specific problems of the tuna fishing industry. Included in the program are service functions as well as basic research in oceanography and biology.

Three principal investigations occupy the research staff: (1) operations research to develop an optimum fishing strategy based on the integrated experience of all segments of the tuna fishing fleets and the results of biological and oceanographic research; (2) oceanographic research to secure information about the tunas and their environment, to understand the distribution of tunas, and eventually make possible predictions of variations in availability; and (3) research on responses and behavior of tunas, to provide scientific information to improve fishing methods. Laboratory scientists work in close cooperation and frequently in collaboration with scientists of the Scripps Institution of Oceanography, the Inter-American Tropical Tuna Commission, and the California Department of Fish and Game. A part of the laboratory's oceanographic research is done under contract to Scripps Institution.

Service functions in oceanography include preparation and distribution of monthly sea-surface temperature charts of the eastern Pacific, useful to tuna fishermen in locating concentrations of tuna, and to marine scientists studying changes in the oceanic environment. The laboratory also has a cooperative endeavor with the University of California in producing a series of topographic charts of the ocean floor for regions of the eastern Pacific. The oceanographic research is directed at analyses of physical, chemical, and biological data, and historical sea-temperature observations to detect features of the environment that have value in predicting time and space occurrence of tunas.

Research on tuna behavior is centered on the phenomenon of schooling. Studies are under way of the vertical distribution of tuna in relation to thermocline depth and of underwater visibility to determine variations in success of purse seine sets as this may be related to avoidance. Laboratory experiments with juvenile scombroids are being conducted to learn about visual stimuli associated with schooling.

Observations at sea are made from research vessels assigned to other Bureau laboratories, oceanographic vessels operated by Scripps Institution and chartered tuna clippers. The Laboratory anticipates operating its own ocean research vessel within three to four years.

The San Diego laboratory is housed in Building 331 of the U. S. Navy Electronics Laboratory at the tip of Point Loma in San Diego. In the summer of 1964, it will move to a new laboratory building, under construction by the Bureau on the campus of the Scripps Institution of Oceanography, University of California at San Diego, La Jolla, some 15 miles north of Point Loma.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, P. O. Box 6317, San Diego 6, California.

Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii

BIOLOGICAL LABORATORY,

HONOLULU, HAWAII

John C. Marr,
Area and Laboratory Director

The research program of this laboratory is designed to increase our knowledge of biological and oceanographic processes in relation to high seas fishery resources, especially the tunas, in the Pacific Ocean.

Work in progress is grouped as follows: oceanography, trade wind zone oceanography, skipjack ecology, albacore ecology, behavior, and subpopulations.

All oceanographic station data available from the Pacific Ocean are being examined to determine (1) average conditions, (2) annual and seasonal variations from the average, and (3) areas in which additional observations are needed. Computing facilities are being used in these studies.

A recent study of all oceanographic data available from a three-million-square-mile area around the Hawaiian Islands, plus heat budget considerations, led to a description of the oceanographic climate of the area and an hypothesis that the major observed annual changes are due to advection effects. A two-year period of intensive observations in the area is planned in order to test the hypothesis (as well as some of the assumptions in the heat budget calculations) and to measure the rates at which oceanographic processes occur.

Owing to the seasonal nature of the occurrence of skipjack, the Hawaiian Islands constitute a natural laboratory for the study of the relationship of skipjack to their environment. It has been observed that the availability of skipjack is directly related to dynamic features of the oceanographic climate; studies are in progress to attempt to learn the nature of this association. Extensive studies of the life history of this species are also in progress.

Observation of tuna at sea, through underwater observation ports, has suggested lines of inquiry hitherto impossible. For example, skipjack exhibit a pattern of vertical bars when feeding, in contrast to their usual pattern of horizontal stripes. This suggests a form of communication; *i.e.*, the behavior of other skipjack may be influenced upon observing this barred pattern. Skipjack prove to be easily conditioned to respond to stimuli, and experiments are in progress to determine their sensory acuity and other factors governing behavior character.

Other problems include the identification of discrete population units, or subpopulations. Results thus far show the existence of several distinct subpopulations of skipjack in the Pacific basin. It would be particularly useful to find a characteristic known to be under genetic control and capable of defining subpopulations. Blood-group systems constitute such a characteristic; several blood-group systems are recognized in tunas.

Most effort has been expended on skipjack and albacore tunas, but these studies now are being expanded to include yellowfin and bigeye tunas, billfishes, and some pelagic sharks.

The existence of special facilities of the Laboratory may be noted, including (1) its location in the trade wind zone of the Pacific, (2) the local availability of several species of tunas, (3) underwater observation ports in the research vessel *Charles H. Gilbert,* (4) extensive collections of zooplankton and bathypelagic fishes, and (5) experimental facilities for studies of behavior-physiology on pelagic predators. Visiting investigators are welcome. Housing is available in Honolulu, but it is relatively expensive.

Address the Area Director, Bureau of Commercial Fisheries, P. O. Box 3830, Honolulu, Hawaii.

ICHTHYOLOGICAL LABORATORY, WASHINGTON, D. C.

Dr. Daniel M. Cohen, Director

This laboratory occupies space in the Natural History Building of the U. S. National Museum in Washington, D. C. The present professional staff consists of two ichthyologists and one malacologist. The objectives of the laboratory are several: (1) original revisional research in systematic zoology; (2) provide technical information on fish, fisheries, and systematics to the Fish and Wildlife Service, other Government agencies and the general public; (3) liaison between the Bureau of Commercial Fisheries and the Smithsonian Institution.

Major research projects presently underway are:

1. A study on the systematics of scombroid fishes, particularly the large, tunalike forms. This is being carried on in cooperation with personnel of the Smithsonian Institution and with the assistance of fishery laboratories and museums all over the world.
2. Contributions to the monographic series *Fishes of the Western North Atlantic.* Sections on clupeoid fishes, benthic Iniomi, and argentinoid fishes have been prepared and editorial assistance has been furnished. At present sections on halfbeaks, needlefishes, and cod-like fishes are being prepared.
3. Studies on continental slope and abyssal fishes of the suborder Ophidioidea.
4. Studies on bivalve mollusks of the family Tellinidae.
5. Studies of the mainly fresh-water fish family Percidae.

The Ichthyological Laboratory does not direct a field program. Personnel from the laboratory have cooperated with field programs of other Government agencies and private institutions and worked in the North Atlantic, the Gulf of Mexico and Caribbean, the North Pacific, and the Tropical Central Pacific.

No accommodations are available for visitors.

Address the Director, Bureau of Commercial Fisheries Ichthyological Laboratory, U. S. National Museum, Washington 25, D. C.

BIOLOGICAL LABORATORY, WASHINGTON, D. C.

Thomas S. Austin, Acting Director

Research at this laboratory is directed to broad geographic aspects of fisheries and oceanography in the Atlantic Ocean. A special responsibility of the Laboratory Director is to plan and coordinate the entire Oceanography Program of the Bureau.

The largest current activity is the Tropical Atlantic Fishery-Oceanography Program, concerned with the equatorial Atlantic as a system for the production of food resources. Specific aspects of research are: (1) physical and chemical properties of environment; (2) processes of organic production; (3) zooplankton fauna and its role in the marine ecosystem; (4) nekton community and its relationship with adacent trophic levels; and (5) distribution, abundance, and biology of the tunas of the Tropical Atlantic. The research vessel *Geronimo* is fully assigned to this program in 1963. Full assignment of the *Geronimo* and a second research vessel is scheduled for 1964 and thereafter. The program, during 1963, is part of the International Cooperative Investigation of the Tropical Atlantic, in which some seven nations are scheduled to participate.

The Environmental Oceanographic Research Program has the principal objective of developing techniques for describing and explaining the geographic distributions of sedentary marine organisms in terms of environmental conditions. Species are selected to demonstrate contrasting distributional characteristics; information on their environmental requirements is obtained by field study; and charts are drawn to show the distribution of limiting environmental factors.

The Oceanographic Instrumentation Program has the following functions: (1) servicing instruments for the laboratory, (2) development of new instruments for the Bureau, and (3) coordination of oceanographic instrumentation development within the Bureau, and with other Government agencies.

The *Geronimo* is a 143-foot ocean-going tug converted for research. Navy docking facilities are available adjacent to the laboratory on the Anacostia River. The Laboratory is designed for a staff of about nineteen investigators and ten technicians. There are accommodations for two visiting investigators. General research facilities are centralized laboratories for processing preserved biological collections, for chemistry, and for oceanographic instrumentation development and testing. There is a small library, a conference room, and nineteen individual offices or office-laboratories for professional staff. There is no special provision for maintenance of living marine life. Emphasis is on facilities for data processing and analysis. There are no living accommodations for visitors, but a variety of reasonably-priced accommodations is available in Washington, D. C., and in the adjacent suburbs of Virginia and Maryland.

The Laboratory is in proximity to several other Government agencies and facilities with oceanographic missions: National Oceanographic Data Center (one block away), Navy Hydrographic Office, National Museum, Geological Survey, Coast and Geodetic Survey, Weather Bureau, and Bureau of Mines. Convenience of contact with these organizations and of access to their large supplies of oceanographic data (hydrological, biological, bathymetrical, geological and meteorological) are definite assets.

The Laboratory is located in Building 74, Washington Navy Yard Annex, Washington 25, D. C. Entrances to the Navy Yard Annex are at 8th and M Streets, S. E. and at 1st and N Streets, S. E.

Address the Director, Bureau of Commercial Fisheries Biological Laboratory, Building 74, Naval Weapons Plant, Washington 25, D. C.

EXPLORATORY FISHING AND GEAR RESEARCH BASES

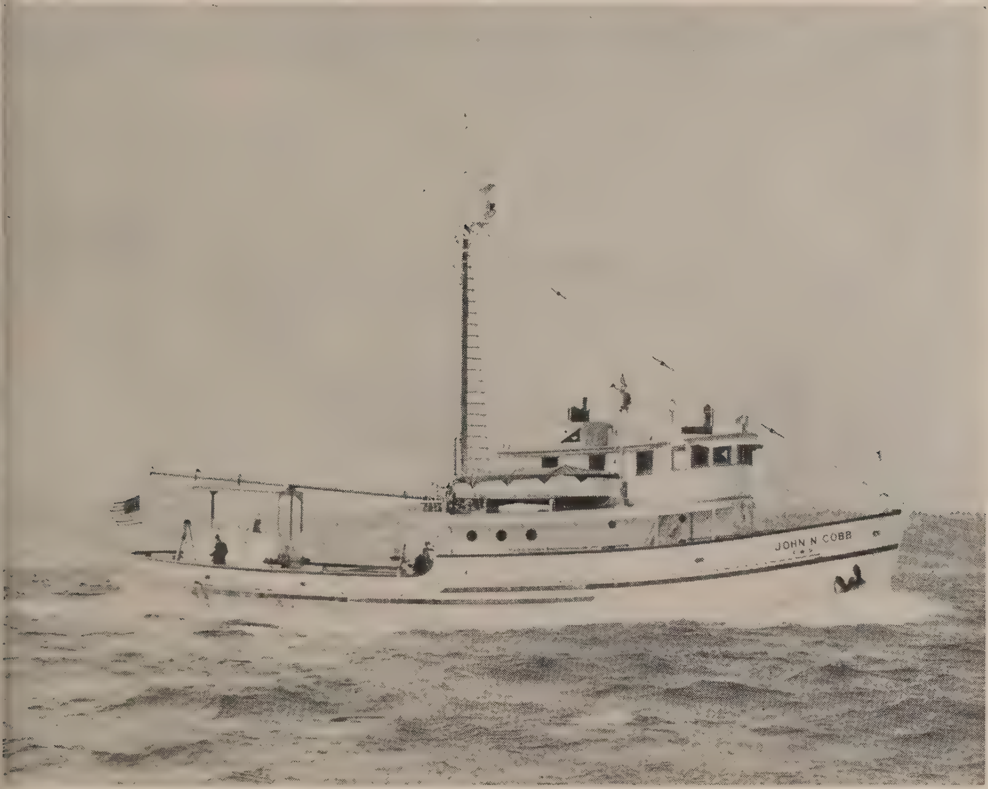
Five Exploratory Fishing Bases, located throughout the United States, are devoted to studies for improved utilization of fisheries resources. The mission for each base is fundamentally research and development in exploratory fishing and gear research. Each base is more or less centrally located in the area for which it is responsible.

Ultimate objectives of the exploratory fishing programs are to define, on a seasonal basis, the quantitative and qualitative distribution of marine resources having a potential for commercial utilization and to provide an appraisal of the commercial value of these resources. Exploratory fishing vessels are equipped with standard and experimental capturing devices and instrumentation useful in navigation, fish detection, and fish capture.

Objectives of the gear research programs are to improve harvesting techniques and devices, and to demonstrate their application to industry. Studies are conducted on fish behavior, and the mechanics and performance of fish-catching devices. This information is applied to designing, modifying, and increasing the effectiveness of fishing gear.

Due to the specific nature of the programs, very limited biological research facilities are available at the exploratory fishing bases. Field collection of indigenous species on a cooperative basis is invited. Catches usually contain a variety of fishes and invertebrates and opportunities for ecological studies are particularly good. Facilities aboard exploratory vessels are available on a first come basis. Cruises and areas to be explored are scheduled well in advance. Address the Base Director of the pertinent Exploratory Fishing Base for information on cruises designed to explore a particular species or geographical area. Living facilities are not provided at the bases themselves, but are generally available in the adjacent areas. Physical facilities at each base house personnel and equipment used in exploratory fishing and gear research, and provide some general and shop working areas. All five bases are readily accessible by boat, rail bus, and private vehicle, with the possible exception of the Region V base at Juneau, Alaska, where accessibility can be seasonally limited.

Accounts of the basic research programs conducted in each geographical region follow. In addition to the included programs, projects specific to particular areas or fisheries are conducted from time to time. For example, the Region II Exploratory Fishing Base (Pascagoula, Mississippi), is currently conducting a two-year exploratory fishing survey of the spiny lobster (*Panulirus*) resource and potential in the Atlantic and Pacific Oceans adjacent to Panama. This survey is being done under a contract with the United States Agency for International Development (AID).



Exploratory fishing vessel *John M. Cobb.* The 93-foot *Cobb* conducts exploratory fishing and gear research in the Northeastern Pacific and is based at Seattle, Washington.

EXPLORATORY FISHING AND GEAR RESEARCH BASE, SEATTLE, WASHINGTON

Dayton L. Alverson, Director

Area stressed: Northeastern Pacific.

Habitat investigated: Bottom exploration of Continental Shelf and slope to 2000 fathoms; coastal and oceanic midwaters.

Vessel: John N. Cobb. Home port: Seattle, Washington. 93-foot wooden exploratory fishing vessel equipped for commercial scale fishing operations. Can accommodate up to two visiting investigators.

Address the Director, Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, 2725 Montlake Boulevard East, Seattle 2, Washington.

The Exploratory Fishing Base, Pascagoula, Mississippi

EXPLORATORY FISHING BASE, PASCAGOULA, MISSISSIPPI

Harvey R. Bullis, Jr., Director

Area stressed: Gulf of Mexico, Caribbean Sea, and the southern North Atlantic Ocean.

Habitat investigated: Bottom exploration of Continental Shelf and slope to 2,000 fathoms; coastal and oceanic midwaters.

Vessels: Oregon. Home port: Pascagoula, Mississippi. 100-foot steel, West Coast-type combination trawler equipped for commercial scale fishing operation. Can accommodate up to four visiting investigators. Primary areas of operation are the Gulf of Mexico, Caribbean Sea, and Central Tropical Atlantic Ocean to Brazil.

Silver Bay. Home port: Brunswick, Georgia (Exploratory Fishing Field Station). 96-foot steel North Atlantic trawler equipped for commercial scale fishing operations. Can accommodate up to four visiting investigators. Primary area of operation is the southwestern North Atlantic Ocean.

George M. Bowers. Home port: Panama City, Florida (Gear Research Field Station). 73-foot wooden shrimp vessel equipped for gear research and development including underwater diving observations. Can accommodate up to two visiting investigators. Primary area of operation is the Gulf of Mexico.

Address Director, Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, Post Office Drawer D Pascagoula, Mississippi.

Bureau of Commercial Fisheries Regional Office, Region 4 Headquarters of the Exploratory Fishing Base, Ann Arbor, Michigan

EXPLORATORY FISHING AND GEAR RESEARCH BASE, ANN ARBOR, MICHIGAN

Melvin L. Greenwood, Director

Area stressed: Great Lakes, principally Lake Michigan and Lake Erie. Farm ponds, lakes, and reservoirs in central United States.

Habitat investigated: Bottom and midwater areas of the Great Lakes, farm ponds, lakes and reservoirs.

Vessel: Kaho. Home port: Saugatuck, Michigan (vessel base). 65-foot steel exploratory fishing vessel equipped for commercial scale fishing operations. Can accommodate up to two visiting investigators.

Address Director, Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, 5 Research Drive, Ann Arbor, Michigan.

EXPLORATORY FISHING AND GEAR RESEARCH BASE, JUNEAU, ALASKA

Warren F. Rathjen, Director

Area stressed: Gulf of Alaska and North Pacific Ocean.

Habitat investigated: Bottom exploration of Continental Shelf and slope; coastal and oceanic mid-waters.

Vessel: No permanent vessel in operation. Field work carried out with chartered vessels which may vary in size, type, and available accommodations. Primary area of operation is the Gulf of Alaska.

Address Director, Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, P. O. Box 2481, Juneau, Alaska.

EXPLORATORY FISHING AND GEAR RESEARCH BASE, GLOUCESTER, MASSACHUSETTS

Keith Smith, Director

Area stressed: North Atlantic Ocean, generally north of North Carolina.

Habitat investigated: Bottom exploration of Continental Shelf and slope; coastal and oceanic waters.

Vessel: Delaware. Home port: Gloucester, Mass. 148-foot steel trawler equipped for commercial scale fishing operations. Can accommodate two to four visiting investigators.

Rorqual. 65-foot vessel for inshore exploration and gear research.

Address the Director, Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, State Fish Pier, Gloucester, Mass.

SUMMARY

The foregoing descriptions of our varied studies of the living resource in its environment represent only a part of the entire Bureau program. We operate five Fishery Technological Laboratories and two Tech-

Exploratory Fishing Base, Gloucester, Massachusetts showing the station and the *M/V Delaware* moored at the adjacent pier.

nological Stations, which conduct scientific studies of nutritive value of fishery products, develop methods for improving quality and attractiveness, and are active in research on fish meal and oil, and on fish protein concentrates for human food.

The Bureau assists the industry with market promotion, carrying out test kitchen research, staging fish cookery demonstrations, cooperating with the States in the National School Lunch Program, and generally educating the consumer in a variety of ways. Economic research and services are concerned with transportation and consumption of fishery products, fishermen's cooperatives, and the effects of foreign competition. Statistical services provide up-to-date information on fisher landings; imports; production; holdings c frozen, canned, or other processed fisher products; and provide a daily market new service to the domestic industry. The Bureau manages the Pribilof fur seal her and reservation and enforces high sea fishery regulations. It is responsible fo administration of three financial program including a Vessel Loan Program, a Fishing Vessel Construction Subsidy Program and a Mortgage Insurance Program. These highlights give a general impression of th diversified and comprehensive program provided by the Federal Government fo the commercial fishing industry of th United States.

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QUALITY OF THE SPAWNING BED AS IT RELATES TO SURVIVAL AND GROWTH OF PINK SALMON EMBRYOS AND ALEVINS AND TIME OF FRY EMERGENCE.

William J. McNeil, Fishery Research Biologist, U. S. Bureau of Commercial Fisheries, Biological Laboratory, Auke Bay, Alaska

Growth, development, and survival of embryos and alevins of salmonid fishes are affected by the availability of dissolved oxygen in spawning beds. The oxygen supply rate to an embryo or alevin is a function of dissolved oxygen content and apparent velocity of intragravel water.

Oxidizing organic detritus, interchange between stream and intragravel water, and permeability of bottom materials exert a significant influence on the amount of oxygen made available to embryos and alevins. Growth and survival of pink salmon (*Oncorhynchus gorbuscha*) embryos and alevins in a small Southeastern Alaska stream were found to be related to these environmental attributes. Evidence was also obtained that fry emergence was delayed where environmental factors were most likely to cause occurrence of oxygen stress during development.

REPRINT

1963
William J. McNeil
Sixteenth International Congress of Zoology
Proceedings Volume 1

APPENDIX C-14

Status of Research on the Improvement of Salmon Spawning Beds in Alaska

lliam J. McNeil, Fishery Research Biologist, U. S. Bureau of Commercial Fisheries

ABSTRACT[1]

Organizations presently participating in studies ating to the improvement of pink salmon spawni grounds in Alaska include: Fisheries Research titute (University of Washington), U. S. Forest rvice, U. S. Bureau of Commercial Fisheries, aska Department of Fish and Game, Ketchikan lp Company, and Institute of Forest Products.

Experiments on the improvement of spawning ds have been undertaken in Indian Creek and rris River, located 40 miles west of Ketchikan. spawning channel with a flood plain designed to duce velocity of flow and turbulence was consucted in Indian Creek. The channel is being aluated to determine utilization by spawning ult pink salmon, egg and larval mortality levels, d channel stability. Experiments on the removal fine particles from spawning beds on egg and larval mortality levels were undertaken in Harris River. Preliminary results of these studies are reported.

The Forest Service plans to construct an additional Indian-Creek type channel near Ketchikan in 1963 or 1964. A third channel may be constructed in Olsen Bay Creek near Cordova in 1965 or 1966. A feasibility study is under way on the development of equipment for removing fine particles from spawning beds, and the construction of a facility to do research on relationships between composition of bottom materials and salmon fry production is being given consideration. There is also much basic research currently underway in Alaska to relate fry production to spawning behavior and environmental stresses.

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[1] *Copies of full text of this report can be obtained from Auke Bay Biological Laboratory, Auke Bay, Alaska.*

Reprint from Report of Second Governors' Conference on Pacific Salmon,
Convened by Governor Albert D. Rosellini of Washington, Hyatt House,
Seattle - January 7-10, 1963.

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From Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No. 6, Vol. 3, P. 1057-1066. 1963.

Methodological Paper No. 5

TUNA BEHAVIOR AND PHYSIOLOGY, A REVIEW

By
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U. S. Bureau of Commercial Fisheries
Biological Laboratory
Honolulu, Hawaii

Abstract

Published data on tuna behavior and to a lesser extent tuna physiology are reviewed. Feeding behavior and schooling behavior are covered more intensely. Data relevant to tuna behavior have been collected primarily by indirect methods, such as examination of stomach contents, distributions of tuna on longlines, etc. The use of sonar is also being expanded. Most studies of tuna behavior require direct observations of the behaving animal. Methods of making direct observations at sea from airplanes, or through underwater portholes in ships have been developed, as have methods of observing tuna directly in captivity. Studies on mackerel also provide information useful in understanding tuna behavior. In the author's opinion ethological study of tuna in captivity will provide the most rapid rate of increase in the understanding of tuna behavior.

COMPORTEMENT ET PHYSIOLOGIE DU THON - REVUE DE NOS CONNAISSANCES

Résumé

Cet article passe en revue les données jusque là publiées concernant le comportement du thon et, à un degré moindre, la physiologie du thon. Il couvre plus largement le comportement de nutrition et le comportement de déplacement en bancs. Les données concernant le comportement du thon ont été réunies d'abord par des méthodes indirectes, telles que l'examen du contenu de l'estomac, la distribution des thons capturés aux longues lignes, etc. L'emploi du sonar s'est également étendu.

La plupart des études sur le comportement du thon demandent des observations directes sur l'animal dans son milieu naturel. Des méthodes d'observations directes à la mer depuis des avions ou par des hublots sous-marins à bord de navires ont été mises au points, et aussi des méthodes d'observations directes en captivité. Les études sur le maquereau ont également fourni des renseignements utiles pour la compréhension du comportement du thon. L'auteur estime personnellement que l'étude éthologique du thon en captivité devrait apporter la contribution la plus importante au progrès rapide de notre connaissance du comportement du thon.

COMPORTAMIENTO Y FISIOLOGIA DEL ATUN: UNA RESENA

Extracto

Se reseñan los datos publicados respecto al comportamiento y, en menor grado, a la fisiología del atún. Se tratan con más detalle el comportamiento durante la alimentación y la agrupación. Los datos relacionados con el comportamiento del atún se han obtenido principalmente por métodos indirectos como el examen del contenido del estómago, distribución en los palangres atuneros, etc.; el sonar es objeto de empleo creciente. Casi todos los estudios del comportamiento del atún exigen observaciones directas del animal y para ello se recurre al aeroplano o a los portillos sumergidos en barcos; también se han hecho observaciones directas en acuarios. Los estudios de la caballa facilitan datos de utilidad en la comprensión del comportamiento del atún. A juicio del autor, el estudio etológico del atún en el cautiverio dará las mayores facilidades para comprender su comportamiento.

1 INTRODUCTION

Behavior as defined by Tinbergen (1951) is the "total movements of the intact animal," and the scientific study of these movements is known as ethology. The theoretical background of ethology, especially as it concerns fish or fisheries biology has been recently reviewed by Baerends (1957), Hoar (1958), and Kesteven (1960). A thorough aquaintance with these fundamentals is essential to the fishery biologist studying tuna behavior.

The purpose of the present paper is to review the published data on tuna behavior and tuna physiology, to point out the methods used to collect such data, and to make suggestions for future work.

Since more information is available on behavior than on physiology, tuna physiology is considered only briefly. The greatest concentration of published information on tuna behavior is concerned with feeding behavior and schooling behavior. Studies with mackerel are used to supplement those on tuna where appropriate.

2 FEEDING BEHAVIOR

2.1 Methods of feeding

Scombrid fishes feed primarily on fish, squid, and zooplankton. An individual fish is capable of finding, catching, and ingesting a cosmopolitan collection of prey, differing greatly in shape, mobility, color, and size (Yuen, 1959; Tester and Nakamura, 1957). This ability results in part from great swimming power, from morphological adaptations present in the feeding apparatus, and apparently from a tendency to behave differently towards different species or types of prey.

Scombrids actively pursue their prey and swallow them intact (Suyehiro, 1942). Their teeth are poorly developed, and prey are not mortally wounded or dismembered before being ingested, although large prey are bitten on the trunk before being swallowed head first (Nakamura, H., 1949). All species except the wahoo, Acanthocybium solandri, have long gill rakers projecting forward from the first gill arch. The rakers presumably prevent the loss of smaller prey through the branchial clefts (Kishinouye, 1923).

Atlantic mackerel, Scomber scombrus, make individual attacks on relatively large sized food objects (Sette, 1950). In this situation the fish no longer orient parallel to each other and schooling is disrupted. Similar disruptions of schooling behavior during feeding have been observed in skipjack, Euthynnus pelamis (-Katsuwonus pelamis) (Nakamura, E., in press; Strasburg and Yuen, 1960a), little tunny, Euthynnus yaito (Tester et al., 1955), and Japanese mackerel, Scomber japonicus (-Pneumatophorus japonicus japonicus) (Hotta, 1960). When feeding on small food particles rather than large ones, Atlantic mackerel do not disrupt their schooling behavior, but instead form dense schools, open their mouths wide, and extend their operculums (Sette, 1950). It is not known whether this latter type of behavior occurs among tuna. Still another reaction to prey was observed by Hiatt and Brock (1948), who reported that little tunny herded prey. In contrast to this apparent cooperation, Allen (1920) observed that a Japanese mackerel, Scomber japonicus, dashing through the water with a 7.5-cm. sardine protruding from both sides of its mouth, was chased by its companions, which grasped at the protruding ends of the sardine and eventually tore the sardine apart.

One very noticeable feeding behavior characteristic of skipjack is a sudden change in coloration from the horizontally striped pattern to one of alternating dark and light vertical bars (Kishinouye, 1923; Strasburg and Yuen, 1960a.; Strasburg and Marr, 1961). This change occurs when skipjack respond to food stimuli, and food stimuli do not release this color change in sated skipjack (Nakamura, E., in press). Transient vertical bars are also visible in photographs of Australian southern bluefin tuna, Thunnus thynnus maccoyii (Serventy, 1956), Chilean bonito, Sarda chiliensis (-Sarda lineolata), and Mexican bonito, Sarda velox (Walford, 1937). These specimens were photographed immediately after they were captured on baited hooks, but no experiments have been conducted to determine whether the color pattern was initiated by food stimuli. It is interesting to speculate that color changes such as those described for skipjack are social releasers of biological significance to the species.

2.2 Food stimuli

Both visual stimuli and invisible chemical extracts of tuna food (smell or taste) release feeding behavior of tuna. Among the visual stimuli, brightness, size, and movement seem to influence the intensity of the feeding response. Light colored or shiny objects resulted in a greater feeding response than dark or dull objects (Hsiao and Tester, 1955; Shomura, 1955; and Tester et al., 1954) presumably because brighter objects were more visible. Increased visibility was also believed to account for higher catch rates of albacore, Thunnus alalunga (-Germo alalunga), with surface trolling lures in waters which were less turbid (Murphy, 1959). Nakamura, E. (in press) observed that partly satiated skipjack responded to small food objects, but not to larger food stimuli. Moving (live) anchovies, Stolephorus purpureus, are more effective as a food stimulus for skipjack at sea than are non-moving (dead) anchovies (Strasburg and Yuen, 1960a.;Yuen, in press).

Invisible chemical extracts of squid, shrimp, and a variety of fish released a feeding response in captive little tunny (Tester et al., 1954, 1955). The extent to which the extracts released feeding behavior was in part influenced by the previous feeding history of the fish. For example, if little tunny were fed shrimp, squid, or tuna flesh, the squid extracts released the most intense feeding responses in the fish which had been fed on squid for the previous week. The same was true of the response to skipjack extracts, among fish fed on skipjack, but was not true for the response to shrimp extracts. The response is not entirely a result of conditioning to the food provided to little tunny in captivity. Those fed squid and baitfish responded to skipjack extracts even though they had never been fed skipjack while in captivity.

According to the principle of heterogenous summation, if an object is characterized by more than one releasing stimulus, i.e. brightness, shape, taste or odor, movement, etc., the presentation of more than one of these stimuli at one time results in a more intense response by the animal. Hsiao and Tester (1955) demonstrated heterogenous summation of food stimuli by little tunny. For example, when neither visual nor chemical stimuli were presented, little tunny remained in the test area 12 percent of the time, when visual food stimuli alone were presented this increased to 24.5 percent, and when both visual and chemical food stimuli were presented this again increased to 29.5 percent. Likewise the number of feeding passes at the visual food stimuli (artificial lures) increased from 14 to 40 passes for a 15-minute period when chemical extracts were added. These results are from experiments with captive tuna, and attempts to increase the response of skipjack to artificial lures on pole-and-line fishing boats at sea by using chemical extracts have been inconclusive or unsuccessful (Tester et al., 1954).

Water sprays from pole-and-line fishing boats onto the surface of the sea increased the biting response of skipjack at sea (Strasburg and Yuen, 1960a.;Yuen, in press). It is not known whether the water spray is a food stimulus itself or acts indirectly by affecting the behavior of the live bait or the appearance of the artificial lures. Different species of live bait also result in different biting rates by skipjack, but this may be largely a consequence of the behavior of the bait in relation to the fishing boat rather than the releasing quality of each prey species (Yuen, in press). Some species, such as the anchovy, tend to swim toward the fishing boat when chased by tuna; other species, such as the goatfish, Mulloidichthys samoensis, tend to dive when chased by tuna.

2.3 Variations in response to food

Many physiological and psychological factors determine the internal feeding motivation and consequently the probability that an animal will respond to a given food stimulus. In Hawaiian waters as few as 43 percent (Royce and Otsu, 1955) and 52 percent (Yuen, 1959) of the skipjack schools contacted by pole-and-line fishing boats yielded any fish, which in turn implies that a large proportion of skipjack schools are not responsive to food stimuli.

Suyehiro (1938) and Hotta et al. (1959) both observed that biting rates of skipjack from a school were higher if the tuna had emptier stomachs. The development of plicae mucosa in the stomach walls was also associated with the emptiness of the stomach and the biting rate. Yuen (1959) observed that skipjack responded to chum for a longer period of time if their stomachs were emptier and if natural prey in the stomachs were in an early stage of digestion. He postulated that fishing boats often exploit a school already in an excited feeding state initiated by naturally occurring prey. Hotta et al. (1959) observed that skipjack with a high frequency of empty stomachs were also captured from poor biting schools and he postulated that the percentage of empty fish in a school determines the overall response of a school to food rather than the stomach volumes of the captured fish. Laboratory experiments (Hotta, 1960) subsequently demonstrated with Japanese mackerel, Scomber japonicus (-Pneumatophorus japonicus japonicus), that if a large percentage of fish in a school had empty stomachs, the school remained in the feeding area for a long time and fed actively. If a small percentage had empty stomachs, the school split into a group of fish congregated about the food and a group of satiated fish swimming at a greater depth. The fish with empty stomachs stopped feeding and joined the deeper school before they themselves ate enough to become satiated. The food consumption of each "hungry" fish in the school was less if a smaller percentage of the school was composed of "hungry" fish.

When skipjack in laboratory tanks were fed as much food as they would consume at hourly intervals throughout the day, the intensity of their response to food rapidly decreased from morning to midday, only to increase slightly again in late afternoon (Nakamura, E., in press). Uda (1940) and Suyehiro (1938) presented data indicating that skipjack bit better in early morning and possibly again later in the day. This pattern was not observed for skipjack in Hawaiian waters (Yuen, 1959). A successful feeding response is difficult to induce in captive skipjack at low light intensities (Nakamura, E., in press) and it is likely that tuna begin the day with empty stomachs. Japanese mackerel (Ii et al., 1953) and Atlantic mackerel (Kittel and Kämpfe,1954) were less active at night than during the day. Stomach volumes of skipjack from the Marquesas Islands and Hawaii followed a diurnal pattern indicating two periods of feeding, the first early in the morning and the second in midafternoon (Nakamura, E., MS). A diurnal rhythm in feeding behavior seems to exist in skipjack and it can be speculated that satiation of the food drive contributes to such a rhythm.

Not only are the volumes of food in the stomach associated with the biting responses of skipjack on pole-and-line fishing boats, but also the species of food in the digestive tract seem to have an influence. Skipjack with fast-swimming fish in their stomachs bit faster and remained near the fishing boat for a longer period of time than skipjack with slow-swimming fish in the stomach (Yuen, 1959). Skipjack schools near Hawaii dove away from the surface for periods of 3 to 28 minutes more frequently if the occurrence of postlarval Synodus variegatus and juvenile Holocentrus lacteoguttatus in the stomachs was high (Strasburg, 1961). Skipjack with a high frequency of small crustaceans in the intestine bit better than those with a high frequency of fish in the intestine (Hotta et al., 1959). Skipjack feeding on natural food of the open ocean bit better than those feeding on coastal prey (Suyehiro, 1938). Mechanistic explanations for these and other similar correlations are difficult to verify at present.

3 SCHOOLING BEHAVIOR

Schooling behavior is observed in all scombrids except the wahoo. Schooling is characterized by a group (school) of fish swimming together in parallel courses with a relatively fixed distance between each fish (Breder, 1959). A definite mutual attraction exists between schooling individuals which in theory is cancelled by a repulsion between individuals when they approach within a certain minimum distance of each other (Parr, 1927; Breder, 1954).

Stimuli which release schooling behavior are mediated primarily by the sense of vision. Chub mackerel, Scomber colias (-Pneumatophorus colias), did not school if they were blinded by piercing their cornea (Shlaifer, 1942) or by placing opaque discs over their eyes (Parr,1927). If the opaque blinders were removed, schooling was immediately resumed. Hatanaka et al. (1957) reported that Japanese mackerel formed a more compact school on dark nights than they did during daylight hours. Yet, in complete darkness chub mackerel did not school (Shlaifer, 1942) even though schooling persisted in deep red light, 650µ - 700µ, and in light intensities so low that the observer could just see the mackerel in the aquarium. Moonlight provided sufficient light for skipjack to school (Nakamura, E., in press). Tuna probably disperse in absolute darkness, but at times light from moonlight or perhaps even from the biological luminescence of zooplankters can be expected to provide enough light for schooling.

Stimuli which release schooling behavior among chub mackerel appear to be associated with the normal swimming movements of a companion and not with its coloration (Shlaifer, 1942). A chub mackerel would not school with a freshly killed companion towed through the water nor with a companion blinded in both eyes and apparently swimming erratically. Schooling did occur among living mackerel painted blue, white, or black.

Yellowfin, Thunnus albacares (-Neothunnus macropterus), and skipjack tend to school with other individuals of the same species and size (Broadhead and Orange, 1960; Brock, 1954). These conclusions are based upon the species composition of purse-seine and pole-and-line catches, and upon the size variability within and between schools. Schooling by species may occur because stimuli which release schooling are for the most part species specific. Brock (1954) hypothesizes that schooling by size results from difference in the swimming speeds of large and small fish. Swimming speeds of Japanese mackerel are more rapid for larger individuals (Hatanaka et al., 1957), but this observation in itself does not verify the swimming speed hypothesis above.

The schooling drive may wane as tuna get older. As mentioned above, schooling behavior is disrupted by feeding behavior. This disruption was apparently complete among large skipjack, 70-80 cm., whereas medium-sized skipjack retained some schooling behavior while feeding, and small skipjack, 20 cm., retained a great deal of schooling behavior while feeding (Strasburg and Yuen, 1960a). In addition, yellowfin caught on adjacent hooks along a longline have a smaller mean length than those caught solitarily along a longline (Brock, 1962). This latter observation indicated that large yellowfin are found in smaller schools than are small yellowfin.

Schooling behavior is relatively easy to observe for surface tuna, but direct observations of schooling behavior among deep-swimming tuna have not yet been made. Evidence for schooling among deep-swimming tuna comes from the distribution of tuna hooked along a set of longline gear. Hirayama (1957) observed a high frequency of tuna on adjacent hooks and by using a mathematical formula calculated a theoretical school width of 1,400-4,500 m. He concluded that a unit this large could not be behaving as a single unit and that the calculated width probably represented an aggregation of schools. The distance between tuna longline hooks is usually 50-60 m. and fish occurring on adjacent hooks in pairs, trios, and even quartets could be expected to represent a unit held together by visual stimuli. Schooling would be indicated if the observed frequencies of such groups were greater than expected from fish distributed randomly along the line. Yellowfin (Brock, 1962; Maeda, 1960; Murphy and Elliot, 1954) and bigeye, Thunnus obesus, (Maeda, 1960) occur on adjacent hooks more often than would be expected by chance. According to Maeda (1960), albacore do not occur on adjacent hooks more often than expected by chance, but an examination of his Fig. 12 indicated that pairs of albacore occur more frequently than expected by chance in 31 out of 40 samples. Apparently deep-swimming schools of yellowfin, bigeye, and albacore do exist.

School size can be estimated if it is assumed that a purse-seine catch contains all the fish from a single school. In the eastern tropical Pacific the average catch per successful set was 12,927 kg. for yellowfin or 12,564 kg. for skipjack (Broadhead and Orange, 1960). In numbers this would be about 1,400 yellowfin and 2,800 skipjack. Although over 75 percent of the yellowfin and skipjack catches in the eastern tropical Pacific are between 227 and 18,144 kg., single sets have yielded as many as 104,326 kg. of yellowfin or 117,934 kg. of skipjack. These catches were estimated from Fig. 9 of Orange et al. (1957). Along the northeastern coast of Japan average catches per successful set of one-boat and two-boat purse seines respectively were 8,253 and 13,504 kg. of bluefin, Thunnus orientalis, 5,777 and 3,264 kg. of yellowfin, or 5,702 and 7,765 kg. of skipjack (Inoue, 1959). Purse seining has been conducted only once in Hawaiian waters and only 590 to 3,828 kg. of skipjack were caught per set even when bait was chummed to hold the fish (Murphy and Niska, 1953). Analyses by Broadhead and Orange (1960) indicate that skipjack schools in the eastern tropical Pacific are larger than those in Hawaiian waters.

4 ASSOCIATIONS

Tuna are frequently sighted at sea in the presence of other species of tuna (Orange et al., 1957; Postel, 1955), sharks (Kimura, 1954;

Uda and Tsukushi, 1934), forage fishes (Kimura, 1954), porpoises (Godsil, 1938), whales (Godsil, 1938; Kimura, 1954; Uda and Tsukushi, 1934), floating logs (Kimura, 1954; Uda and Tsukushi, 1934; Yabe and Mori, 1950), bamboo rafts (Kojima, 1960), etc. The percentage occurrence of these associations with skipjack varies markedly with geographical area and time of year (Kimura, 1954; Orange et al., 1957; Uda and Tsukushi, 1934).

Associations between tuna species, tuna and birds, tuna and porpoises, and in some cases tuna and whales or sharks may be based upon a common interest in the same concentration of prey. Birds were observed to follow tuna and to prey upon small fish chased to the surface by tuna (Godsil, 1938; Royce and Otsu, 1955). Tuna fishermen take advantage of this association and locate tuna schools by seeking bird flocks. They even make inferences about the behavior of the tuna from the birds' behavior. The possibility that tuna use birds, porpoises, whales, or other tuna in locating concentrations of prey also exists.

Association with sharks also results from predation by sharks on tuna (Bullis, 1961; Springer, 1957).

Uda (1933) stated that skipjack concentrated about whale sharks, fin whales, sei whales, and floating logs to escape predators. Observations which lend some support to this statement were reported by Gudger (1940). Hypotheses mentioned by Yabe and Mori (1950) for association with floating logs are that tuna seek the shade of a floating object or that forage is more abundant near a floating object. Since tuna were not found in association with floating seaweed which would provide both shade and forage fish, Yabe and Mori (1950) argue that neither shade nor food is a factor. They further discounted food because drift-log schools took bait readily and did not appear to have a high abundance of small fish or zooplankters in their stomachs. Shade was considered unimportant by Kojima (1960), who observed that tuna and other fishes under anchored bamboo rafts did not stay in the shade but instead oriented upstream from the raft along the anchor line. Observations by divers under a salvage ship led Damant (1921) to conclude that the shadow of the ship made zooplankton more visible to mackerel which collected under the ship and fed on the zooplankters. Available evidence does not lead to a ready explanation for the association between tuna and whales or floating objects.

5 MIGRATORY BEHAVIOR

Tuna have long been known to make extensive migrations (Sella, 1929). In the Pacific tagged albacore have been recaptured as many as 6,920 km.from the place at which they were tagged, and have averaged as much as 0.98 km. per hour during a 287-day period between time of release and recapture (Otsu, 1960). Such data and data on other species indicate that tuna possess highly developed orientation mechanisms which make directed movements across the seas possible. No work has been conducted to delineate these mechanisms for tuna, but kinesis in respect to temperature gradients and orientation in respect to celestial bodies or the angle of their light rays are two possibilities.

6 LOCOMOTION

Skipjack swim continually with their mouths agape, and pectoral fins slightly extended (Nakamura, E., in press). The first dorsal and pelvic fins are also extended during turns and all fins, including second dorsal, anal, and ventral fins, are extended during sudden deceleration. Swimming speeds of skipjack in a feeding school have been clocked at sea at 6.4-7.7 meters per second (Watanabe, 1942).

7 REPRODUCTIVE BEHAVIOR

Observations of reproductive behavior have not been reported.

8 SENSORY PERCEPTION

The eyes of Japanese mackerel have a lower ratio of twin to single cones than do non-scombrid fishes dwelling at depths of 100-300 meters, and Tamura (1957) postulated that twin cones are more sensitive to low light intensities than are single cones. Although cone densities are higher in the posterior half of the retina, indicating greater acuity to the front, no area of the retina is highly specialized for acute vision. The ratio of highest cone density to lowest cone density from different areas of the retina is only 1.21, whereas in non-scombrids this ratio is as high as 7.46.

According to Tamura (1957), the even distribution of cones may have advantages to pelagic fishes by providing balanced vision in all directions. Estimates of visual acuity based upon the angle subtended by one cone indicated that relative to other fishes the Japanese mackerel has average acuity.

A well developed pineal apparatus, consisting of a pineal window, pineal tube, pineal dome, and pineal organ, has been described in bluefin, Thunnus thynnus, and many other scombrids by Rivas (1953) and Holmgren (1958). These structures permit light to be transmitted from the top of the fish's head to the pineal region of the brain. The pineal tube is at an angle of 20°-30° from the vertical and would be expected to pass the greatest amount of light to the pineal region when the sun was 45°-60° above the horizon (Rivas, 1953). Rivas postulated that the pineal apparatus is involved in the positive phototaxis described by Hsiao (1952) for yellowfin and little tunny in response to light intensities between 70 and 450 ft.-c. Although histological and anatomical evidence for a sensory role of the pineal apparatus in tuna is good, this has not been verified with behavior data (Holmgren, 1958).

Tester et al. (1955) and van Weel (1952) demonstrated that tuna are able to perceive tastes or odors found in extracts of shrimp, squid, and tuna flesh. The detectable substance (substances) did not appear to be a fatty acid or lipoid, an amino acid or protein, or a purine but in many respects chemically resembled vitamin B_{12}. Tuna were also repelled to a small degree by copper acetate, a shark repellant.

The characteristics of a sense of hearing have not been described for tuna. The Japanese mackerel turned away from a small explosion if the sound intensity exceeded 58 db. and responded to the sound of a bat hitting a wooden barrel at intensities of 35-38 db. (Suyehiro et al., 1957).

9 PHYSIOLOGY

Scombrids bring oxygenated water in contact with the gill filaments by swimming continually with their mouth agape. When forward motion of a mackerel was impeded, oxygen saturation of the blood decreased from 85 percent to 11 percent (Hall, 1930). In contradiction to the above, Kittel and Kämpfe (1955) reported that Atlantic mackerel come to rest near the bottom at night. The anatomical structures necessary for pumping oxygenated water over the gills are poorly developed. Gray (1954) found that the gill area for Atlantic mackerel was 1158 mm.^{2} per gram of body weight. This was the second highest relative gill area among 17 temperate-zone marine fishes examined. Oxygen capacity of the blood, 15.77 ml. oxygen per 100 ml. of blood (Root, 1931), and the amount of iron, 43.8 mg. per 100 ml. of blood (Hall, 1930), were also high relative to other fishes. Scombrids are apparently capable of providing relatively large amounts of oxygen to their body tissues, which is not surprising when their high activity levels are considered. Oxygen consumption by a 138-g. mackerel was given by Baldwin (1923) as 0.726 cc. of oxygen per gram of body weight per hour, which was the highest rate among eight marine fishes he examined. High metabolic rates are also indicated by body temperatures of yellowfin, bigeye, and skipjack, which are apparently 1°-4° C. higher than the temperature of the surrounding water (Nakamura, H., 1941; Watanabe, 1942; Uda, 1941).

Amount of food eaten per unit body weight, relative growth rate, and efficiency of food conversion decreased as the size of Japanese mackerel increased (Hatanaka and Takahashi, 1956; Hatanaka et al., 1957). Mackerel 33 g. in weight, reared at 20°-22° C. and fed as much anchovy as they would eat, ingested 18 percent of their body weight per day with a 20-percent conversion efficiency, whereas mackerel 73 g. in weight ingested only 10 percent of their body weight per day with a 15-percent conversion efficiency. Feeding rates, growth rates, and conversion efficiencies were lower at lower temperatures. Immediately after a period of starvation mackerel ate more, grew faster, and had higher conversion efficiencies than they did 10 days after the period of starvation ended. When amounts of food given per day were increased, feeding rates and growth rates increased, but efficiency of conversion decreased. Estimated amounts of food needed to just maintain body weight were 4.7, 4.1, and 3.6 percent of body weight for 7-24 g., 26-48 g., and 50-95 g. mackerel respectively. Daily rates of catabolism, estimated from daily loss in weight when not fed at all, were 1.96, 1.12, and 0.80 percent of body weight for 7-24 g., 26-48 g., and 50-95 g. mackerel respectively. A comparison f anchovy and Euphausia as food demonstrated hat conversion efficiency was less for Euphausia. atanaka et al. (1957) believe that the lower fficiency with Euphausia may result from the arger proportion of indigestible material in Euphausia compared to anchovy. The above exeriments yielded higher growth rates than were bserved in natural populations of mackerel, and atanaka et al. (1957) estimated that growth ates observed in nature would be approximated f a young-of-the-year mackerel ingested 375 g. f anchovy and 1553 g. of Euphausia during the ear, and if a one-year-old mackerel ingested 68 g. of anchovy and 3660 g. of Euphausia in a ear. The ratio of Euphausia to anchovy was etermined from the occurrence of these two ypes of food in mackerel at sea.

Studies on Japanese mackerel indicated that after eating to satiation the stomach contents were reduced in volume by about 90 percent after 8 or 10 ours (Kariya, 1956). At that time the contents ad been reduced to gurry which was moved into he intestine 21 hours after ingestion. At intervals after satiation food was eaten approximately equal in volume to the amount of food removed rom the stomach by digestive processes. During he digestive process the stomach contents are acidic (Kariya, 1956).

Although additional information is available on tuna physiology, especially in the Japanese literature, no attempt was made to review it at this time.

10 METHODS OF STUDY

Methods of collecting data useful in describing and understanding behavior of tuna include (1) indirect observations on tuna at sea, (2) direct observations of tuna at sea, (3) direct observations on captive tuna, (4) comparative studies of tuna anatomy and histology, and (5) any of the methods, referred to above, which have been used to study mackerel or other species closely related to tuna. Indirect observations at sea have been obtained with sonar (Anonymous, 1953; Anonymous, 1961; Lozano Cabo, 1959; Nishimura, 1961), from observations on bird flocks, from tagging and recapture data, from spatial distributions of tuna on longlines, and from catch rates, stomach contents, and associated data from purse-seine and pole-and-line fishing. Most published data relevant to tuna behavior have been collected by these indirect methods.

Except for observations through the water's surface from ships, direct observations at sea of behaving tuna are a very recent advance. At present observations are made from underwater ports in surface vessels (Strasburg and Yuen, 1960b.), from low flying aircraft (Royce and Otsu, 1955; Hotta et al., 1961), by SCUBA divers from floating rafts (Kojima, 1960), from small wet submersibles, and in the future observations using mesoscaphes may be practical (Zaitsev and Azhazha, 1959). Direct observations are necessary for most types of behavior studies and are a prerequisite to the description and understanding of tuna behavior. Such observations are difficult to obtain at sea, since the proportion of time spent actually observing behavior is low owing to difficulties in either keeping the observer near the tuna or, conversely, the tuna near the observer. Many of these difficulties can be removed by using captive tuna in shoreside enclosures or tanks for study. Work by Tester (1952), and Nakamura, E. (1960, in press) have demonstrated that studies on captive fish, although difficult, are now possible. Ethograms can be made and analyzed, salinity and temperature preferences can be measured, sensory acuity, motivation, and learning can be studied. Inferences about behavior and clues as to what to look for in behavior can result from studies of anatomy and histology. These studies are more useful if they are comparative in scope. Much of the detailed information on schooling and feeding behavior presented in the present summary have had to be generalized from studies on mackerel because equivalent data are not available on tuna. These studies are most useful and will continue to be useful, because there are many similarities between mackerel and tuna, and because mackerel are more easily handled in the laboratory.

11 THE FUTURE

The above summary of information on the behavior of tuna demonstrates the presence of many unknowns and many unverified hypotheses. An overwhelming number of potentially fruitful studies await the researcher of tuna behavior. Accurate descriptions of behavior characteristics, the basis of any ethological study, have not been completed, much less compiled into feeding ethograms, reproductive ethograms, etc. The physiological basis and the ecological consequences of behavior provide opportunities for study of color changes, fin movements, mouth movements, diving behavior, sensory systems, etc. Sensory acuity is unknown for vision or sound perception. Mechanisms of migration orientation are unknown for tuna. Phototaxis and the potential role of the pineal apparatus should be clarified. An ethological explanation of size and species homogeneity of schools can be expected to result from careful experimentation, as can ethological explanations for associations between tuna and porpoise, whales, or floating logs. Studies are needed on detailed histology and anatomy of sense organs, central nervous system, and muscular system. As many or more unknowns are to be found in tuna physiology as in behavior.

The greatest advances in the study of fish behavior have come from studies conducted on species easily reared in the laboratory. Although many papers are to be found in fishery literature which pertain to tuna behavior, ethological and psychological literature contain no papers on tuna. The present status of our knowledge on tuna behavior suffers from difficulties in studying the animals inexpensively in the laboratory. Newly found skills, such as the ability to raise tuna in captivity, the ability to make direct observations at sea, and the ability to follow their movements with sonar, will provide the tools for many interesting studies in the future.

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From Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. FAO Fisheries Reports No. 6, Vol. 3, P. 1011-1021. 1963.

Methodological Paper No. 2

SUBPOPULATION IDENTIFICATION

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Abstract

The methodology of subpopulation identification includes morphometric studies, tagging experiments, blood group studies, and miscellaneous other studies. The methodology of each is reviewed. Blood group studies are particularly attractive, since they permit the study of characteristics under genetic control.

Although some advances have been made in morphometric studies, results obtained are frequently equivocal. Important results have been obtained from tagging experiments on albacore in the North Pacific, yellowfin and oceanic skipjack in the eastern Pacific, and oceanic skipjack in the central Pacific. Blood group studies have only recently commenced, but interesting results have been obtained for albacore in the Pacific and Indian Oceans, and for oceanic skipjack and bigeye in the central Pacific.

The major tasks of identifying tuna subpopulations remain. It is to be hoped that basic problems will not be lost sight of in the pressure of solution of pressing practical problems.

IDENTIFICATION DES SOUS-POPULATIONS

Résumé

Les méthodes d'identification des sous-populations comprennent des études morphométriques, des expériences de marquage, des études de groupes sanguins et diverses autres analyses annexes. L'article passe en revue la méthodologie de ces différents types d'études. Les études des groupes sanguins présentent un attrait particulier, car elles permettent d'examiner les caractéristiques soumises à l'influence de la génétique.

Bien que les études morphométriques aient fait quelques progrès, les résultats obtenus sont encore souvent incertains. Des résultats importants ont été obtenus avec des essais de marquage effectués sur le thon germon du Pacifique Nord, sur le thon à

nageoires jaunes du Pacifique oriental et sur la bonite océanique à ventre rayé du Pacifique oriental et central. Les études des groupes sanguins sont encore très récentes, mais des résultats intéressants ont été déjà réunis sur le thon germon des océans Pacifique et Indien, sur la bonite océanique à ventre rayé et sur le thon obèse du Pacifique central.

Les travaux les plus importants sur l'identification des sous-populations de thons restent encore à faire. On souhaite que les problèmes fondamentaux ne soient pas négligés sous la pression des problèmes pratiques à résoudre.

IDENTIFICACION DE SUBPOBLACIONES

Extracto

La metodología de identificación de subpoblaciones incluye estudios morfométricos, de grupos de sangre y varios otros, y experimentos de mercado. Se reseña la metodología de cada uno. Los reconocimientos de los grupos de sangre son de especial interés porque permiten estudiar las características bajo control genético.

Aunque se han hecho algunos adelantos en los estudios morfométricos, los resultados obtenidos son con frecuencia equívocos. Se han logrado importantes resultados en los experimentos de marcado de albacora en el norte, de atún de aleta amarilla y barrilete en el este, y de barrilete en el centro del Pacífico. Los estudios de grupos de sangre sólo se han iniciado recientemente, pero se han obtenido resultados interesantes para la albacora en los océanos Pacífico e Indico y para el barrilete y patudo en el Pacífico central.

Quedan por dilucidarse las principales cuestiones relacionadas con la identificación de subpoblaciones de atún y es de esperar que no se pierdan de vista los problemas fundamentales, por tener que encontrar solución urgentemente a los problemas prácticos.

1 INTRODUCTION

Even as the tunas are cosmopolitan creatures, so are the tuna fisheries cosmopolitan in nature. The products of these fisheries compete in a world market. Furthermore, the yield of the world tuna fisheries has about doubled in the last decade and it has been estimated (Chapman, In Press) that it will double again in the next decade or decade and a half.

The nature of the fisheries and the trend of increasing world yield contribute a large element of urgency to the problem of subpopulation identification. Subpopulation identification involves the recognition and definition of self-sustaining population units. I prefer the term "subpopulation" for such natural units, but will also use the terms "population unit" and "interbreeding population" as exact synonyms.

The importance of subpopulation identification has been recognized for more than half a century and has been reviewed extensively in recent years. There seems to be little point in plowing the same field at length here. Rather, it is sufficient (1) to emphasize that subpopulations are interbreeding groups with genetic continuity within units and genetic discontinuity between units and (2) to provide references to the recent reviews of the problem (Marr, 1957, In Press; Marr and Sprague, In Press; Mužinić, In Press; Mužinić and Marr, In Press).

2 METHODOLOGY

Of the methods available for the study of subpopulations, two classical methods have been widely applied to the tunas, with the recent addition of a third method borrowed from other disciplines. The classical methods are the study of body proportions, or morphometrics, and tagging experiments. The newer method is that of studying blood group systems by immunological techniques.

2.1 Morphometrics

The study of morphometrics involves the comparison of one or, usually, several body proportions among two or more samples. Originally such comparisons were made on the basis of ratios, i.e., head length/body length (Heldt, 1931). Subsequently, comparison of ratios was generally abandoned in favor of regression analysis of original variates, thereby avoiding difficulties introduced by allometric growth and intercepts not passing through the origin (Marr, 1955).

Among the tuna morphometric studies making use of regression analysis may be mentioned the works of Broadhead (1959), Frade (1931), Godsil (1948), Hennemuth (1959), Hiyama and Kurogane (1962), Postel (1956), Royce (1953), and Schaefer (1955). (No effort will be made to supply a complete list of references. Such are available in the annotated bibliographies of Corwin (1930), Shimada (1951), Van Campen (In Press), and Van Campen and Hoven (1956).)

In general, these works involved individual comparisons, of the body proportions used, between pairs of samples. For example, if data on 15 body dimensions were available in three samples from different localities, then body dimension 1 would be compared between areas A and B, between B and C, C and A, and so on for the other 14 dimensions, making a total of 45 comparisons. If a significant difference (at whatever probability level the investigator was willing to gamble) was found between particular samples, it was generally (but not universally) concluded that the samples had been drawn from distinct population units.

It is possible, especially in the case of large samples, to find significant differences even though the data show considerable overlap. Royce (1957, In Press) greatly advanced the methodology of morphometric comparisons in two respects. First, he pointed out that significant differences in the presence of overlap do not indicate that the samples represent distinct units, but rather that they were not drawn from the identical unit. In fact, the amount of overlap is a measure of the amount of mixing that could occur. The amount that actually does occur would have to be determined by independent means, such as a tagging experiment. Second, he extended and modified existing methods so that it is possible to compare several dimensions simultaneously. This adds greatly to the power of the tool.

In spite of these advances, there remains one major source of uncertainty in interpreting results. It is known for several species of fishes that body form is modified by the environment (for example, by temperature during the early life history, by food supply, etc.) Although such environmental modification of body form has not been experimentally verified in the case of the tunas, there is no reason to believe that it does not obtain for these species as well. Thus, significant differences in tuna dimensions may be indicative of environmental differences, rather than of subpopulation differences.

2.2 Tagging experiments

Tagging experiments (and the related marking experiments) have been a tool of the fishery biologist for practically as long as there has been a field of fishery biology. It has only been within the past decade, however, that the technique has been applied to the tunas with any degree of success.

Perhaps the earliest successful tuna tagging experiments were those performed unintentionally. Sella (1929) and Heldt (1932) have reported on hooks recovered from bluefin tuna in the Mediterranean and eastern Atlantic. Because of the unique characteristics of hooks used in different fisheries, it was possible to infer movements on the basis of hook recoveries. Such recoveries were, of course, infrequent.

Early attempts to tag tunas employed tags attached around, or to, the caudal peduncle. The numbers of individuals tagged in these experiments were generally small. The earliest tuna tagging was probably that of Sella in 1911, who placed tags around the caudal peduncles of 10 bluefin tuna (Rounsefell and Kask, 1945). Similar tagging experiments include those of Frade and Dentinho (1935), on bluefin tuna, and of various Japanese workers, Fukuda and Iizuka (1940) for example, on oceanic skipjack. Recoveries from these tagging experiments were either zero or few in number and occurred over a short period of time. These results are not surprising in view of Sette's (1950) experimental results with tags around the caudal peduncles of Atlantic mackerel.

There followed a series of experiments involving, generally, regions other than the caudal peduncle. The most extensive of these was by Godsil (1936, 1938a, 1938b), who tagged 4,000 yellowfin and oceanic skipjack with opercular strap tags. Other experiments, involving relatively small numbers of fish, include bluefin tagged with opercular disks by Westman and Neville (1942), albacore tagged with button tags through the tail (Scagel, 1949), albacore tagged with "break-away" hooks (Partlo, 1950), albacore tagged with a Peterson tag through the base of the second dorsal fin (Powell, 1950), and albacore tagged with a plastic streamer tag (Schaefers, 1952).

According to Marr (in press):

"Large-scale tuna tagging experiments commenced with the development of the plastic loop or 'spaghetti' tag by Wilson (1953), following the earlier work of Alverson and Chenoweth (1951), Powell et al. (1952) and Schaefers (1952). This tag, a section of vinyl tubing, is applied through the muscle of the dorsal surface posterior to the second dorsal fin. The free ends are tied together after the tag is in place.

"Subsequent improvements, as judged by increased recovery rates, have arisen from modifications in (1) materials and methods of application resulting in longer tag life, (2) tagging technique resulting in a reduction of the time during which the fish is out of water and in the amount of handling to which it is subjected and (3) materials and techniques resulting in a greater recognition rate of recaptured fish.

"Modifications of the first type include the use of a clamp instead of a knot to secure the free ends of the tag, a tag core of monofilament nylon and the use of a different vinyl tubing capable of withstanding longer exposure to sea water (Schaefer, 1958).

"Modifications of the second type include not measuring the length of the tagged fish, the use of an automatic clamping device for securing the free ends of the tag (Schaefer, 1958) and the use of a dart tag (Yamashita and Waldron, 1958). With the dart tag, oceanic skipjack (Katsuwonus pelamis) can be hooked, tagged and released in as little as four to seven seconds (Waldron, personal communication), as contrasted to 20 seconds for loop tags (Yamashita and Waldron, 1959). Modifications of the third type include more conspicuous tag color (Blunt and Messersmith, 1960; Schaefer, 1958) and an attractive reward system (Schaefer, 1958)."

A stainless steel and plastic streamer dart tag has also been used by Mather (1960) and Mather and Bartlett (1962) to tag bluefin tuna and other large fishes without removing them from the ocean.

The dart tag is the most successful tuna tag yet developed. Tagging experiments on oceanic skipjack have shown a recovery rate with dart tags at least an order of magnitude greater than with loop tags (Blunt and Messersmith, 1960; Yamashita and Waldron, 1958). In view of the short period of time involved in catching, tagging and releasing an individual fish, it is unlikely that there will be any great improvements in this general type of tagging. Perhaps the next advance will involve tagging tuna in situ with radioisotopes, although there are obvious problems here.

2.3 Blood group systems

Although blood group systems in man have been known for over a half-century (Landsteiner, 1901), such systems have only recently been investigated in tunas, or in fishes, for that matter. Blood group systems are known to be under genetic control in every animal in which this question has been considered, including man, chickens, cattle, goats, rabbits, and goldfish. The methodology employed in the study of blood group systems is that of immunology.

The use of blood group system studies as a tool in identifying subpopulations has two important features. The first of these is that the characteristics studied are under genetic control. Thus, for the first time, it is possible to study genetic make-up directly and with assurance. In the case of morphometric characteristics, their genetic nature is assumed or hoped for. In the case of tagging experiments, only inferences about gene flow may be drawn (although in some cases the probabilities associated with such inferences are quite high). The second reason, following from the first, is that the power of this tool exceeds that of any other available tool. For example, it is not only possible to compare samples with respect to whether or not they represent the same subpopulation, but it is also possible to determine if a single sample represents a single subpopulation or a mixture of two or more subpopulations.

According to Marr and Sprague (In Press):

"The methods of pursuing such studies are, as already indicated, through the techniques of immunology. Initially, the investigator must acquire a set of antisera or reagents that will identify one or more of the blood groups present in the species of interest. Such reagents may be developed by the introduction of red blood cells of the species being studied into other individuals of the same species, into individuals of other species, or more rarely, they may occur naturally in the same or other species. It has been found (Mäkelä, 1957; Bird, 1959) that extracts of the seeds of many legumes are very useful in this regard. The exact nature of the "antibodies" in the legume seeds is not known, but they are proteins, probably globulins (Boyd et al., 1958).

"Exploratory classification of samples of the species under study will proceed, of course, simultaneously with the development of antisera. At some point the investigator will be satisfied that the antisera can identify one or more blood groups and will begin to examine series of samples from appropriate localities. Since erythrocytes are frequently difficult to preserve for any length of time, this may mean quite literally taking the tests to sea.

"Through the use of this technique, samples of a subpopulation are not ordinarily classified according to the presence or absence of a single characteristic. In fact, most blood group systems are genetically quite complex, having more than two alleles; 6 - 9 alleles are not uncommon, and one blood group system in cattle has more than one hundred and fifty.[1] It follows, then, that samples are classified according to the frequency of presence or absence of several characteristics. Thus, in comparing samples, there still exists the problem (which fishery biologists constantly encounter) of making sample-size adequate to enable distinction between observational error and real differences between samples. . . .

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[1] "It should be pointed out that, lacking genetic information, the recognition of a particular blood group system as a 2-, 3-, 4-, or X-allele system is an assumption."

"There is a further quality of genetic characteristics which adds great power to the use of this tool. In the presence of random mating,[1] and assuming no mutation or selection effects, the frequencies of alleles p, q ... x will occur in proportions according to the expansion of the binomial. This condition will obtain after only one generation of random mating and will persist thereafter. This general concept is known as the Hardy-Weinberg Law. It follows, then, that single samples can be examined to determine whether or not they conform to this law. If a sample does not conform to the Hardy-Weinberg Law, it may be concluded that it was not drawn from an interbreeding population; i.e., it was composed of individuals of two or more interbreeding populations. If a sample does conform to the Hardy-Weinberg Law, the data are consonant with the hypothesis and it may be concluded that the sample was drawn from an interbreeding population."

Marr and Sprague (in press) have summarized the advantages and disadvantages of the use of blood group systems in the study of subpopulations as follows:

"Advantages:

1. The characteristics studied are genetic.
2. Not only can samples be compared, but single samples can be examined with respect to whether or not they were drawn from a single subpopulation.
3. The statistical procedures involved are simple.
4. Recaptures (or a fishery) are not required.

"Disadvantages:

1. Blood preservation may be a problem. If it is, the method must be taken to sea.
2. Developing reagents may be difficult and time consuming.
3. In order for the full power of the technique to be realized, blood group systems must be identified and it must be possible to recognize one more phenotype than the number of recognized alleles. (This provides the degree of freedom necessary for Hardy-Weinberg analyses.)"

It should be pointed out that, lacking enough information for Hardy-Weinberg analysis, the danger of erroneous interpretation of blood group data exists. If, unknown to the investigator, individuals from two subpopulations mix during the non-spawning season and if the relative proportions of the two vary from area to area, it might be possible to observe significantly different frequencies, in different areas, of the blood group characteristics being studied. This possibility would be obviated if it were possible to restrict sampling to spawning assemblages. Moreover, in the one species (Sardinops caerulea) for which data bearing on this possibility exist, fish from two subpopulations may be found in the same geographic area, but not within the same school (see below).

2.4 Other methods

There are several other methods which have been, or might be, applied to the problem of identifying tuna subpopulations. Perhaps the commonest of these is the use of meristic characters, such as numbers of gill rakers, fin rays, finlets, etc. Where data on such characters have been examined, they have frequently been reported with morphometric data. The method of analysis is that of comparing frequency distributions.

Some work has been done at the species level, and might be applicable to levels of lesser differentiation, with serum protein antigens and soluble muscle tissue antigens through the use of the Ouchterlony method of diffusion precipitin analysis (Ridgway, 1962). It was concluded, however, that the use of serum proteins and muscle tissue was not as promising as the use of red blood cells (i.e., the study of blood group systems). There is the further question of whether or not these compounds (serum proteins and soluble muscle substances) are under strict genetic control.

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[1] "Random mating refers not to random mating between individuals, but rather to random combinations within a gene system."

Other work at the species level includes attempts to identify tuna larvae through paper chromatography extraction of amino acids (Matsumoto, 1960). The further application of this method is not indicated, since the amino acids present can be influenced by diet (Farris, 1957, 1958) and, in any case, the order of appearance of amino acids, rather than the kinds present, would be expected to be under genetic control.

Investigation of sperm morphology, through electron microscopy, as a possible means of distinguishing subpopulations is in progress (Inter-American Tropical Tuna Commission). These studies are not yet sufficiently advanced to demonstrate whether or not the method will have utility. In this same category is work in progress (California Department of Fish and Game) on the electrophoresis of soluble proteins from the eye lens. Similarly, Fujii et al. (1962) have examined the base composition of testis DNA of tunas.

Other methods, for example studies of parasite faunas, that have been applied to other species have not been used on the tunas.

3 IMPORTANT ADVANCES

3.1 Morphometrics

Important advances in the methodology of morphometric studies include (1) regression analysis of original variates rather than ratios, (2) the realization that overlapping distributions, even though significantly different, indicate the possibility of mixing and, in fact, that the amount of overlap sets an upper limit on the possible amount of mixing, and (3) the development of methods permitting the comparison of several characteristics simultaneously.

As for results, i.e., the definition of subpopulations, obtained with this method, it may be said that they have been somewhat equivocal. Perhaps the best evidence in support of this statement is the vigor with which other, more effective methods have been sought. Reference to the results of some of the morphometric studies of albacore, oceanic skipjack, and yellowfin in the Pacific will serve to illustrate the point.

In a preliminary study, based upon small numbers of fish, Godsil (1948) advanced the working hypothesis that the albacore taken off North America were "probably distinct and nonintermingling" with those taken off Japan. Subsequent tagging experiments demonstrate trans-North Pacific albacore migrations; blood group data support the hypothesis of a single North Pacific albacore subpopulation.

Hennemuth (1959) examined morphometric data on oceanic skipjack from French Oceania, the Hawaiian Islands, and the eastern tropical Pacific. No differences were observed between samples from French Oceania, nor between samples from the Hawaiian Islands. Differences were found between these areas, but it was not possible to rule out the possibility that these were "observer" differences. Differences were found between four areas in the eastern Pacific, as well as between these areas and the central Pacific area.

Hennemuth concluded:

> "These morphometric comparisons of skipjack indicate that there is a lack of complete mixing of populations between the Central and Eastern Pacific, and that there is a lack of complete mixing among different areas in the Eastern Pacific. Whether or not some mixing between [the Central and Eastern Pacific] and [within the Eastern Pacific] occurs cannot be determined from these data, however, because of the small differences in body proportions with which we are dealing here, and because of the various sampling difficulties. It is doubted whether further investigations of racial structure of skipjack in these regions by morphometry will be very fruitful."

Tagging experiments have shown no interchange of skipjack between the Hawaiian Islands and the eastern Pacific. (The fishery in French Oceania is only at a subsistence level, so the chances of recovering tagged tuna there are slight.) Blood group studies demonstrate a difference between (1) the Hawaiian Islands, (2) the Society and Tuamotu Islands, and (3) the Marquesas Islands. (A comparison between these areas and the eastern Pacific has not yet been made.) Within the eastern Pacific area, tagging experiments have not shown exchanges between the areas separated by about 15° N. South of 15° N., tag recoveries indicate rather wide movements. North of 15° N., tag recoveries indicate much less movement. Nevertheless, Schaefer et al. (1961:358) apparently regard the oceanic skipjack of the eastern Pacific as part of a single subpopulation of much greater range:

"The evidence for lack of far-westward migration of skipjack is much less impressive, and it is, in our opinion, quite possible that the skipjack population supporting the fishery adjacent to the American coast is only a portion of a population which ranges far to the westward."

Morphometric studies of yellowfin have been made by a number of people, including Godsil (1948), Schaefer (1952, 1955), Broadhead (1959), and Royce (in press). The general conclusion has been that there is little or no mixing between the eastern Pacific and other areas. Royce (in press) concluded, however, that limited mixing in an east-west direction along the equatorial region was possible, (for example, less than 50 percent overlap (= maximum possible mixing) between samples 1,500 miles apart), although the data did not show whether such mixing did in fact take place.

Godsil (1948) found differences within the eastern Pacific region but concluded that the yellowfin of that region were probably of a single subpopulation. Broadhead (1959) found differences between areas within the eastern Pacific region, but these were of the same magnitude as were found within areas. He therefore concluded that the yellowfin of the region belonged to a single subpopulation.

Yellowfin tagged in the eastern Pacific have not been recovered in other areas; the tagging results thus tend to confirm the distinctness of eastern Pacific yellowfin. Recoveries within the eastern Pacific, plus other data, have, however, led Schaefer (1961:75-6) to suggest the presence of two subpopulations in the eastern Pacific:

"These data on yellowfin migrations, together with other knowledge (size composition of catch, spawning areas) lead us to suspect that we may be dealing with a northerly sub-population of yellowfin tuna which is largely confined to the region north of 15° N latitude, but some of whose members range some degrees further south, and another, southerly sub-population with its center off Central America, but ranging north to abou 16° N and south to at least the vicinity of the Gulf of Guayaquil, there being an area of over-lap of these population components along a stretch of coast in the vicinity of the Gulf of Tehuantepec."

In general, the author believes it is fair to state that because of sampling problems, mea-surement error, and inconclusiveness of results, attempts to distinguish subpopulations on the basis of morphometric characteristics are being abandoned in favor of other, more promising methods.

3.2 Tagging

Important advances in the methodology incl (1) the development of the plastic, spaghetti tag and (2) the subsequent evolution of this tag, and of tagging methods, culminating in the plastic dart tag.

Perhaps the most spectacular advance in di tinguishing subpopulations of tunas through tagging has been the results obtained from albacor tagging experiments in the north Pacific (summarized by Otsu and Uchida, in press; Clemen 1961). Although the limited data do not establi conclusively the existence of a single subpopula tion of north Pacific albacore, they do demonstrate trans-Pacific migrations. Furthermore because of the tagging results, it has been possible to erect a model of albacore migration in the north Pacific, based on all available data, that is consonant with the existence of a single subpopulation. Limited blood group data support this hypothesis.

Equally suggestive, although based on much fewer data, are trans-Atlantic migrations of tagged bluefin tuna (Mather, 1960).

Much more extensive tagging experiments on oceanic skipjack and yellowfin have been carried out in the eastern tropical Pacific (Blunt and Messrsmith, 1960; Schaefer et al., 1961). The tagging results, although not necessarily the interpretation of the results, of these individuals are essentially similar. The work of Schaefer et al. (1961:357-9) may be quoted:

"One of the most striking and important results of the tagging of yellowfin and skipjack tunas in the region of the fishery off the coast of the Americas is the indication that they are much less migratory than might have been expected. Evidence from the tag recoveries is that they do not migrate, in large numbers at least, to other regions of the Pacific Ocean, and that, even within the Eastern Pacific region, the fish are not rapidly mixed.

"Through December 1959, we had recovered 747 tagged yellowfin tunas and 937 tagged skipjack. In addition, Blunt and Messersmith (1960) have reported the recovery of 263 yellowfin and 237 skipjack tagged in the Eastern Pacific. All of these have been recovered in the region of the fishery off the Americas; none has been returned from regions to the westward."

And:

"It is to be noted that a large share of our recoveries of yellowfin tuna and skipjack has been made within a few months of tagging. Yet a considerable number has been made a year or more after liberation. . . . If there were any very substantial portion of the fish tagged in the Eastern Pacific moving to other parts of the ocean where much fishing is done, we would expect to get at least a few recoveries from such regions.

"In the case of yellowfin tuna, the evidence of lack of significant migration far to the westward is fairly convincing. There is a substantial fishery throughout the Equatorial Central Pacific, regularly extending eastward to 110° or 120° W. longitude, conducted by Japanese longline vessels, which would be expected to capture some of our tagged fish if they moved westward into that region. It is, of course, possible that too few of the small yellowfin we have tagged survive to reach the larger sizes taken on longline gear, or that tagged fish were captured on such gear but the tags were not returned to us. However, the negative evidence from the tag returns confirms the conclusion of independence of yellowfin stocks in the Eastern and Central Pacific. . . based on morphological differences.

"The evidence for lack of far-westward migration of skipjack is much less impressive, and it is, in our opinion, quite possible that the skipjack population supporting the fishery adjacent to the American coast is only a portion of a population which ranges far to westward. There is no substantial fishery for skipjack anywhere in the Central Pacific, except the rather minor fishery near the Hawaiian Islands. [Of some 13,000 skipjack tagged in the Hawaiian Islands region, about 10 percent have been recovered in that region, none elsewhere.] Such tagged skipjack as might migrate westward would thus have little or no opportunity to be captured. Nor have morphological studies revealed any indications of differences between the skipjack of the Eastern and Central Pacific (Hennemuth, 1959). [But see p. 7 above.] The western extent of the range of the skipjack population supporting our fishery remains, thus, an open question.

"Even within the range of the fishery in the Eastern Pacific, the migrations of these tropical tunas are rather less extensive than one might believe *a priori*. . . . At this time we wish to point out only the substantial share of the recoveries which have been made within fifty or a hundred miles of the tagging locality, even after many months at liberty. These tunas, at least at the sizes we have tagged, are obviously not roaming rapidly all over the range from California to Peru."

I have already quoted Schaefer's (1961) suspicion that there may be northern and southern subpopulations of yellowfin, separated at about 15° N. I have also pointed out that this same division is discernible in the skipjack tagging results.

While the evidence from tagging is much more definitive than that from morphometric studies, and in some cases is quite striking, it is nevertheless clear that we are apt to be dealing with complicated situations in nature and the results of tagging experiments may be expected to be equally complicated.

3.3 Blood group systems

In my opinion, the application of immunogenetic techniques to the study of subpopulations in tunas will prove to be the single greatest methodological advance in this area. The application of these techniques is so recent, however, that results are not yet abundant. But there are data available bearing upon the subpopulation problem in albacore, oceanic skipjack and bigeye.

Suzuki et al. (1959) presented data on a blood group system, designated Tg1-Tg2-O, in albacore from the northwestern Pacific (southeast of Honshu) and from the eastern Indian Ocean (largely southwest of Sunda Strait). The observed frequencies in the samples from the two areas showed striking differences. Marr and Sprague (In Press) suggested that the data represent a three-allele system, analogous to the A-B-O system in man. Further, by Hardy-Weinberg analysis they showed that the North Pacific data represented a single subpopulation, while the Indian Ocean data represented a mixture of two or more subpopulations. This is in accord with the results of tagging experiments in the North Pacific. There have been no tagging experiments in the Indian Ocean.

Sprague (1962) reported on a blood group system, designated C, in albacore from the North and South Pacific. He believed this to be a two-allele system in which the phenotypes are either C-positive or C-negative. Samples from North America in 1960 and 1961 showed consistent proportions of the two phenotypes. A sample from Samoa in 1961 was significantly different. However, Dr. Sprague has informed me (personal communication) that subsequent work with additional samples and reagents suggests that a greater number of alleles is involved and a separation merely on the basis of proportions of C-positive and C-negative is not as clear-cut as first appeared to be the case.

Sprague and Holloway (In Press) and Sprague, Holloway, and Nakashima (In Press) have presented information on blood group studies of oceanic skipjack, albacore, bigeye, and yellowfin. Their data were adequate to consider the subpopulation problem only for oceanic skipjack and bigeye. On the basis of phenotype frequencies in a system in oceanic skipjack termed the B system, differences were found between (1) the Hawaiian Islands, (2) the Marquesas Islands, and (3) the Tuamotu and Society Islands. They interpret the data as indicating the existence of three subpopulations. However, as they suggest, since the data do not permit Hardy-Weinberg analysis, a minimum of two subpopulations could be involved, mixing to varying degrees in the three areas. This is probably unlikely, but is a possibility.

A three-allele blood group system analogous to the human A-B-O system has been found by Sprague et al. (In Press) in bigeye. This system has been termed the A-B-O system (although it is not related to the human A-B-O system except by analogy). Data from the Hawaiian Islands permit Hardy-Weinberg analysis, and it was thus possible to show that the sample represented a single subpopulation.

Although not concerned with tunas, two additional studies of blood group systems in fishes may be mentioned. The first of them (Sindermann and Mairs, 1961) describes a three-allele A-B-O analog in the spiny dogfish. The observed frequencies conformed to the Hardy-Weinberg Law; the sample represents a single subpopulation. The interesting feature of this work is that it was possible to compare the blood types of pregnant females with those of their unborn pups. The results of these comparisons were consonant with a three-allele system.

The other study (Sprague and Vrooman, In Press) provides information on subpopulations of the sardine of the northeast Pacific. Because of these blood group data and other kinds of data (tagging experiments, space-time distribution of spawning, etc.), more is known about the subpopulation structure of this species than of any other fish. The possible existence of subpopulations has been recognized for some time (Marr, 1957) on the basis of the existence of four space-time spawning groups. Sprague and Vrooman were able to identify two subpopulations on the basis of a C blood group system. These probably correspond to the fish spawning off southern California and those spawning off central Baja California. I understand (press release dated April 13, 1962) that sardines in the Gulf of California have recently been found to be characterized by different proportions of C-positive and C-negative fish than the previously identified subpopulations.

It is known from these blood group data and from tagging experiments that fish from the two subpopulations off southern California and Baja California may occur in the same geographic area, probably at or about at the same time. However, they apparently do not occur in the same schools, since no schools have been found to contain intermediate proportions of C-positive and C-negative fish. The reason for this apparent lack of intra-school mixing even during the non-spawning period is not known but may be related to the facts that (1) sardines tend to school by size and (2) northward migrations tend to be size-specific, so that fish of the same size from the two subpopulations may not occur in the same area at the same time.

Continued exciting results may be expected from the application of this technique to the problem of distinguishing tuna subpopulations. It is to be hoped that knowledge of the blood group systems used will be such that Hardy-Weinberg analyses will be possible and that each subpopulation will be identified by more than one blood group system.

4 REMAINING PROBLEMS

Although a promising start has been made on the identification of tuna subpopulations, the main tasks of identification and range delimitation lie before us. These problems still exist for all tuna species in all oceans.

If the kinds of remaining problems are categorized, the first is that of improving methodology. This is not so much a matter of improving present methods as it is developing completely new methods or, as is more likely, adopting methods presently being used in other fields. As useful as tagging experiments and immunogenetic studies may be, it should be kept in mind that different methods may offer other advantages.

The second category, as already indicated, is that of identifying subpopulations and delimiting their ranges, for all tuna species in all oceans. This is obviously a goal that will not be soon attained. Some choices will have to be made in the order in which these many problems will be attacked; specifically, what species in what localities will be studied first. The choices may be dictated by economic (i.e., fishery) problems. Examples of tuna subpopulation problems, the solution of which would have reasonably immediate applications, include the yellowfin of the eastern Pacific, the albacore of the North Pacific, and the oceanic skipjack of the Hawaiian Islands region. Undoubtedly there are other examples.

On the other hand, a good case can be made for basing the choice of which problem to attack first on the one considered most likely of solution. If there is a tuna subpopulation problem which present knowledge and judgment indicates is most susceptible of solution, enough might be learned in its solution to increase the rate of solution of similar problems attacked subsequently. A problem selected on this basis might or might not coincide with one selected on an economic basis.

The third category is that of the application of the knowledge of subpopulations in the study of other problems. Foremost among them are the fishery-oriented problems which, in fact, give rise to the study of subpopulations. These include the population dynamics of subpopulations and the equally important, but perhaps less well appreciated, ecology of subpopulations.

Other problems, of less immediate application but certainly of long range importance, include in situ studies of population genetics, studies of tuna genetics, and studies of comparative evolution. It is to be hoped that basic studies such as these will not be overlooked as a result of the pressure of more immediate problems.

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1.

Note on the Return Rate of Tagged Skipjack, *Katsuwonus pelamis*, and the Effects of Handling

By

JOHN C. MARR*

rge-scale tuna tagging experiments commenced the development of the plastic loop or "spaghetti" by Wilson (1953), following the earlier work of rson and Chenoweth (1951), Powell et al. (1952) Schaefers (1952). This tag, a section of vinyl ng, is applied through the muscle of the dorsal ce posterior to the second dorsal fin. The free are tied together after the tag is in place.

bsequent improvements, as judged by increased rn rates, have arisen from modifications in (1) erials and methods of application, resulting in er tag life; (2) tagging technique, resulting in a ction of the time during which the fish is out ater and in the amount of handling to which it is ected; (3) materials and techniques, resulting in eater discovery rate of recaptured fish.

odifications of the first type include the use of a p instead of a knot to secure the free ends of the a tag core of monofilament nylon, and the use different vinyl tubing capable of withstanding ger exposure to sea water (Schaefer, 1958).

odifications of the second type include not suring the length of the tagged fish, the use of an matic clamping device for securing the free ends he tag (Schaefer, 1958), and the use of a dart tag mashita and Waldron, 1958). With the dart tag, nic skipjack (*Katsuwonus pelamis*) can be hooked, ged and released in as little as four to seven nds (Waldron, personal communication), as trasted to 20 seconds for loop tags (Yamashita Waldron, 1959). Modifications of the third type ude more conspicuous tag color (Blunt and Messer- th, 1960; Schaefer, 1958) and an attractive reward em (Schaefer, 1958).

kipjack are perhaps the most delicate of the tunas have shown the greatest improvement in the rn rate of tagged individuals as a result of retion in tagging time and concomitant handling. example, Blunt and Messersmith (1960) report turn rate of 2.56% from 742 skipjack tagged with t tags and 0.29% from 695 tagged with loop tags, n experiment in which the two types of tags were lied to alternate fish in the eastern tropical Pacific. mashita and Waldron (1958) report a return rate of 0.61% from 1961 skipjack tagged with loop tags in the vicinity of the Hawaiian Islands between 1954 and 1956. They also report a return rate of 9.15% from 8161 skipjack tagged with dart tags in the same area in 1957. Tagging mortality is apparently directly proportional to the time and handling required by tagging. The experience of the Honolulu Laboratory staff members in establishing skipjack in captivity clearly supports this conclusion.

Nakamura (MS) has recently reported on the establishment and behavior of skipjack in captivity. Initial attempts involved catching skipjack with barbless hooks, carrying them from the fishing racks to a bait well into which they were released, returning to port, removing the fish from the bait well and carrying them about 50 yards to an experimental tank. Ten attempts, involving 44 skipjack as well as two *Euthynnus yaito* and two *Coryphaena hippurus*, were made in this manner. All fish died within 48 hours. Various refinements, including carrying the fish in water-filled plastic bags and the use of thorazine, made no apparent difference in survival rate.

These difficulties led to the use of a portable tank. Skipjack caught with barbless hooks were lowered into the portable tank and allowed to shed the hook. When the ship returned to port, the portable tank was lifted (by crane) from the ship, carried to the experimental tank and lowered into it. Once in place, a hatch on the side of the portable tank was opened, the skipjack swam out into the experimental tank and the portable tank was removed. Thus, the fish were not directly handled and, in fact, did not come in contact with any foreign object except the barbless hook.

Two lots of skipjack have been introduced into the experimental tank in this manner. They exhibited little bruising and did not swim at high speeds nor bump into the tank walls, as did fish introduced in the original manner. Fish of the first lot survived for as long as 73 days and of the second lot for as long as 173 days. Food was taken on the ninth day by fish of the first lot and on the second day by fish of the second lot. After they began to feed, the fish were easily conditioned to an artificial stimulus for feeding. Death probably resulted from dietary insufficiencies, rather than other environmental conditions, and almost certainly not from handling.

Director, Hawaii Area, U. S. Bureau of Commercial eries, P. O. Box 3830, Honolulu 12, Hawaii.

Summary

Return rates of tagged skipjack were increased approximately tenfold with dart tags in comparison with loop or "spaghetti" tags. Increased return rates were presumably a reflection of increased survival rates resulting from decreased handling and time out of water. This conclusion is supported by evidence from attempts to establish skipjack in captivity. Such attempts were successful only when the skipjack were not directly handled and came in contact with no foreign objects except a barbless hook.

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37.

A Model of the Population Biology of the Pacific Sardine *Sardinops caerulea*[1]

By

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History of the sardine fishery

The fishery for the sardine, *Sardinops caerulea* (Girard), in the Pacific began to grow in the second decade of this century and in ten to twenty years became one of the world's great fisheries. A decline in landings began in the late 1940's and reached catastrophic proportions in the early 1950's. The decline was not instantaneous, nor consistent; neither was it identical at all of the major landing areas, which included San Pedro, Monterey and San Francisco, California, and Britisk Columbia, Canada. The annual landings from 1916–17 through 1958–59 are shown in Figure 1. At present the fishery exists only at a low level at San Pedro, with occasional resurgences to central California.

The greatest development in the fishery came through the use of purse seines. Other forms of gear had been used, including lampara nets and even, in the very early history of the fishery, beach seines. Although sardines occur well offshore at certain times, the fishery was concentrated in coastal regions. In California, fishing was generally carried out at night, during the dark of the moon, and the schools were generally located by bioluminescence (of plankton). The fishing season was in the autumn and winter. In Canada, fishing was generally carried out during daylight. The season was in the summer and autumn. Although this is an oversimplification, the distribution of the fishing localities in space and time resulted from the annual migration pattern of the sardine; north in the spring and summer, south in the autumn and winter.

The great growth of the fishery was possible because of the economics of the meal and oil industry, rather than the canned product.

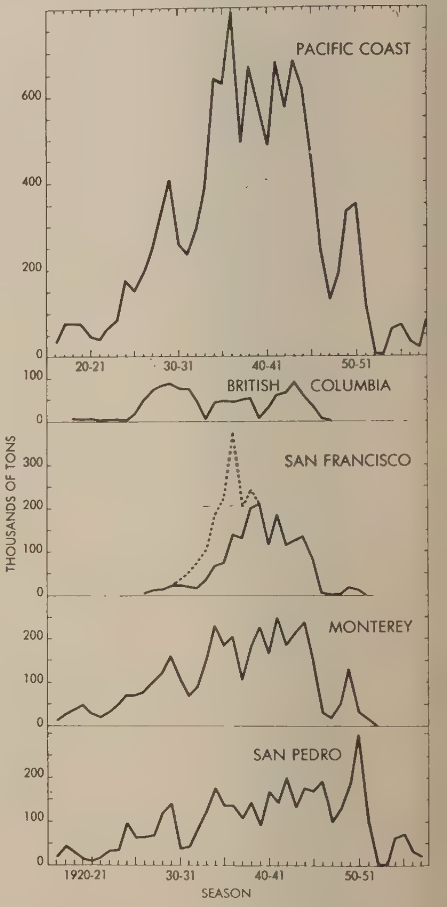

Figure 1. Sardine landings, in 1,000s of tons, along the coast of North America (excluding minor amounts lan Mexico). Broken line in San Francisco panel indicates a landed at floating reduction plants. This and all subs figures are from Marr (1962).

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[1] This paper is taken almost entirely from a more detailed report (Marr, 1962) prepared for the FAO World Scientific Meeting on the Biology of Sardines and Related Species, Rome, 1959.

auses of the decline

n North America, at least, the recent course of the rdine fishery has come to be regarded as a classic ample of the decline of a fishery. Because of great terest, inherent as well as economic, in this decline, ny explanations have been advanced. Some of these ave been intuitive; a smaller number have been based n sophisticated models. In general, and as might be xpected, they tended to fall into one or the other of wo broad categories: the decline was attributed either to the fishery or to natural causes (generally unspecified). All of these explanations had, I believe, one thing n common. None of them took all available information in account.

ontemplation of all available information has led to a model that offers an explanation of the decline. In brief, I believe that the fishery has declined owing to a reduction in sardine population size and range; that population has been reduced because of a relavely long series of small year-classes; and that this series of small year-classes has resulted from unfavourable environmental conditions rather than a reduction in the size of the spawning population. The specific features of the model are the following.

a) Sardines produced in the spring on the spawning grounds off southern California and central Baja California, Mexico, contribute the bulk, or all, of the ted States and Canadian landings (see Figure 2 for location of spawning grounds.)

b) Sardines produced on the southern California spawning grounds migrate as far north as British Columbia, support the fishery there and contribute to the heries at San Francisco, Monterey, and San Pedro.

c) Sardines produced on the central Baja California spawning grounds migrate as far north as central ifornia and contribute to the California fisheries, ecially at San Pedro.

d) Lack of spawning success on the southern California spawning grounds since about 1943 could thus count for the observed changes in the fishery.

e) Lack of spawning success on the southern California spawning grounds has not resulted from lack of wning, but rather from a below-average temperature regime that has acted to delay spawning and place eggs and larvae out of phase with their normal vironment.

f) I suggest that the interaction between sardine rvae and their environment, under the temperature posed delay, is mediated through competition with chovy larvae, which species has a lower temperare threshold.

g) The temperature regime is determined by anographic conditions, such that low temperatures nd high salinities) occur under conditions of above-average north-west winds, whereas high temperatures (and high salinities) occur under conditions of below-average north-west winds.

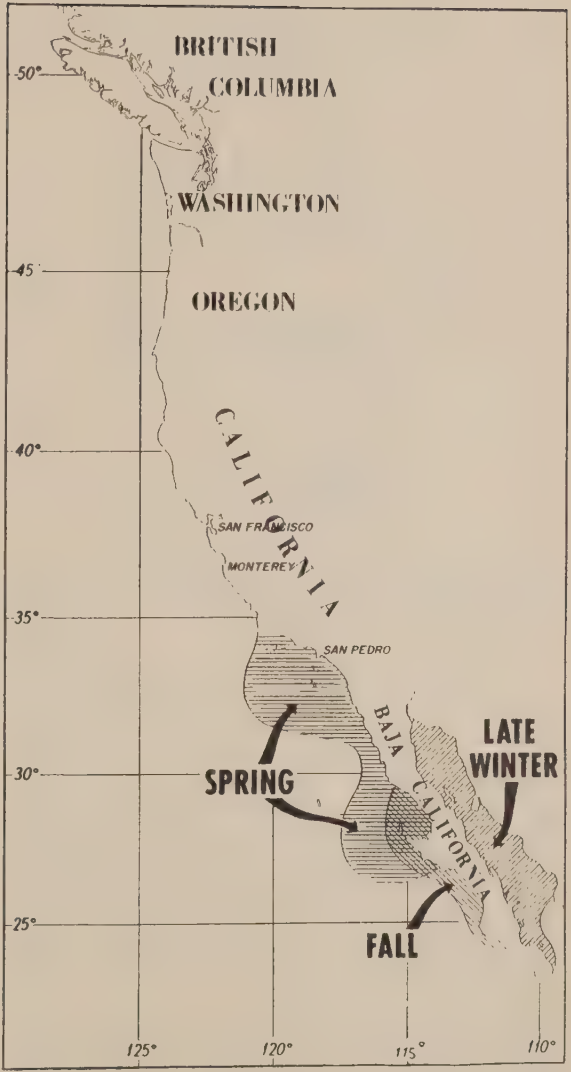


Figure 2. Schematic representation of the location of sardine spawning areas.

Comparison of model with data

If this model is realistic even in a descriptive sense, there are a large number of data with which it must be consonant. (In addition, if it is realistic in a dynamic sense, there must be some process relating population size and environment.) A comparison between descriptive features and the model follows.

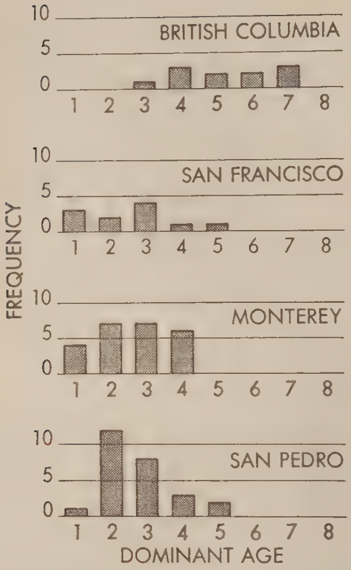


Figure 3. Frequency distributions of ages dominant in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro.

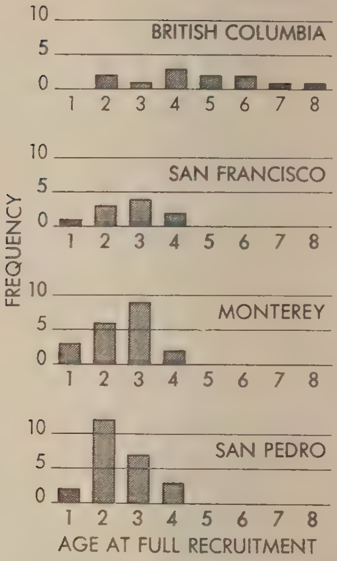


Figure 4. Frequency distributions of ages at which year
were fully recruited into the sardine fishery at British Col
San Francisco, Monterey and San Pedro.

(a) *Location and magnitude of catch.* There was a general decline in total catch and a progressive decline from north to south (see Figure 1). This is what would be expected if, for practical purposes, the last successful spawning off southern California was in 1943.

(b) *Year-class composition of the catch.* All year-classes subsequent to the 1943-class were essentially absent in British Columbia and in reduced numbers elsewhere, especially in central California. (The 1948-class was predominantly a southern year-class.) Again under the model, this would be expected if the last successful spawning off southern California was in 1943.

(c) *Dominant age in the catch and age at full recruitment.* Age 1 is more frequently dominant at Monterey and San Francisco than at San Pedro. Age 2 is clearly the dominant age at San Pedro (see Figure 3). The most common age at full recruitment is 2 at San Pedro and 3 at Monterey (see Figure 4). These features may be explained by differing migration times from the two spawning areas to the fishing grounds. It would be expected on the basis of distance, and is borne out by tagging experiments, that it requires a longer period of time for fish from the central Baja California spawning area to reach the San Pedro fishery than it does for fish from the southern California spawning grounds to reach the central California fishery. Thus, age 1 is more commonly dominant in central California than southern California. The fact that age 3 is the common age at full recruitment at Monterey could be a
tion of increasingly greater northward migrati
southern year-classes with increasing age.

(d) *Average growth during first year of life.* In
and earlier years, sardines experienced a dif
growth history during their first year of life tha
did in 1944 and subsequent years (see Figure 5). I
ences in time of spawning on the two spawning gr
and density dependence (year-class size) may b
minated, although not categorically, as possible
of this difference in growth history. Rather, the
be attributed to differences in food supply. Rei
(1958) have demonstrated a negative associatio
tween surface temperatures and plankton volum
the area off southern California and northern
California. Thus, in the earlier warm years
successful spawning was possible in both areas, p
ton volumes were low and there was less food pe
In the more recent cool years, when it is postu
that successful spawning was possible only off c
Baja California, plankton volumes were high and
was more food per fish. (Although there are
changes in plankton composition from year to
I assume that, in general, as plankton volumes in
the constituents that are sardine food will also incr

(e) *Growth (length-on-age) curves.* Sardines sar
in British Columbia tend to have a slower initial g
and attain greater age and size, than do those sar
at San Pedro, which have a greater initial growt

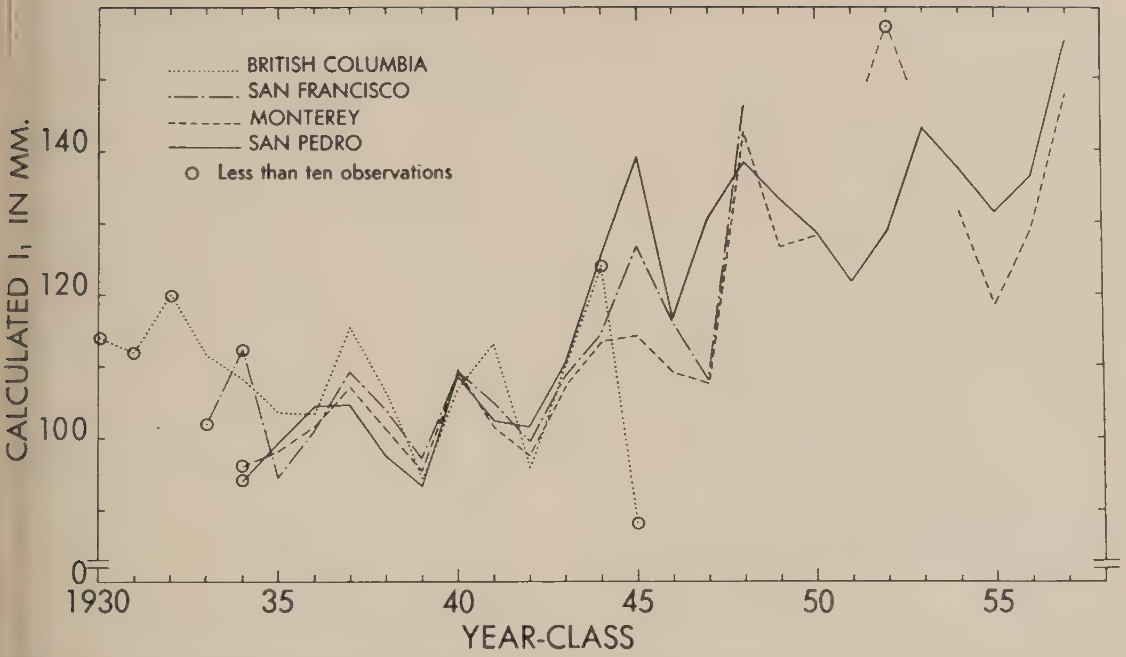


Figure 5. Average calculated length at the end of the first year of life (l_1) of sardine year-classes at British Columbia, San Francisco, Monterey and San Pedro.

ain a lesser size and age. However, at older ages nd greater sizes) the growth of fish from San Pedro sembles that of fish from British Columbia. The owth of fish sampled in central California is inter- ediate between these two extremes, but most closely sembles that of fish from British Columbia (see Fi- ure 6). Even though growth during the first year tends be similar, it is to be expected that during the course their life, fish produced on the central Baja Califor- a spawning grounds will, on the average, experience armer temperatures than will fish produced on the uthern California spawning grounds. Their growth stories should show concomitant differences. South- n fish may be expected to have a more accelerated istence and grow rapidly, but have a reduced longe- ty. Northern fish may be expected to grow more owly, but to attain greater age and size. In general, appears that the differences observed between the shing areas correspond to what would be expected om appropriate, according to the model, mixtures of sh from the two spawning grounds.

f) *Movements as revealed by tagging.* In the tagging xperiments carried out before the second war, fish ere tagged off Baja California, southern and central alifornia, and British Columbia. Recoveries were made in all areas, save Baja California where there were no recovery facilities. Fish tagged north of Baja California tended to be recovered in all areas. However, of fish tagged off Baja California, three-fourths of the recoveries were made in San Pedro and one-fourth in central California. This is in accord with the differential migration of fish from the two spawning areas proposed in the model.

(g) *Spawning areas.* The existence of two spawning areas has already been indicated (see Figure 2). This figure also shows two additional spawning areas. These have been ignored in the model. Either fish from these latter areas do not contribute to the U. S. and Canadian fisheries to an important degree or, if they do, may account for discrepancies between observation and the model.

(h) *Year-class size.* The various year-classes have not been equally abundant on the several fishing grounds (see Figure 7). For example, the 1939-class was relatively more abundant in the north and the 1948-class was relatively more abundant in the south. Such differences may be accounted for by varying success of spawning in the two spawning areas, plus the differential migrations according to area of origin.

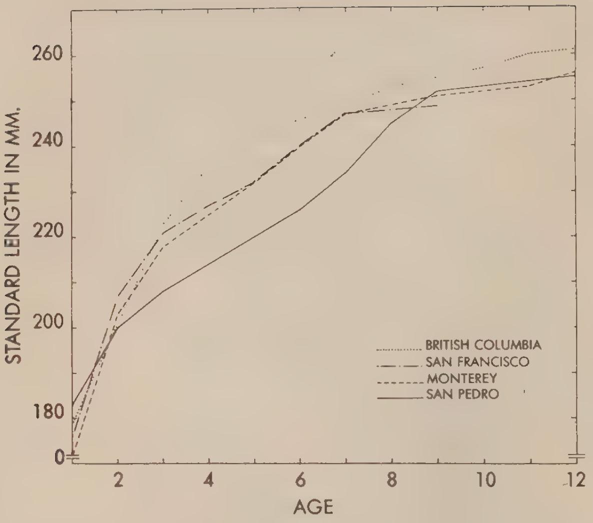


Figure 6. Average size at successive ages of fish in the sardine catch at British Columbia, San Francisco, Monterey and San Pedro.

Other models: causal mechanism

The first four points of my model are thus seen to conform reasonably well to observation. Before considering the last three points, which relate to a causal mechanism, it is pertinent to review other previously proposed models.

Schaefer (1954) has presented a model in which it is assumed that population growth is density dependent, that fishing mortality is the major cause of changes in population size and, hence, that by controlling fishing removals from the population it is possible to maximize yield. This implies that recruitment, that is, year-class strength, is density dependent (or that environmentally produced variations in recruitment are small with respect to density produced variations). According to his model, when catch per unit effort data are plotted as a function of effort, the data should lie about a line of equilibrium conditions. It has been possible to add data for four additional seasons to his figure (see Fig. 8). They all lie below and to the left of the line of equilibrium conditions, such that the entire array of points appear to be varying about a horizontal line. I have concluded that his model is not applicable to the sardine.

A perhaps more direct approach to the problem of density dependent population growth (in numbers) has been the attempt to determine the relationship, if any, between spawning stock size and year-class size. This has been considered in some detail (Clark and Marr, 1955) and it was my conclusion that the spawning stock strength at which year-class size is a

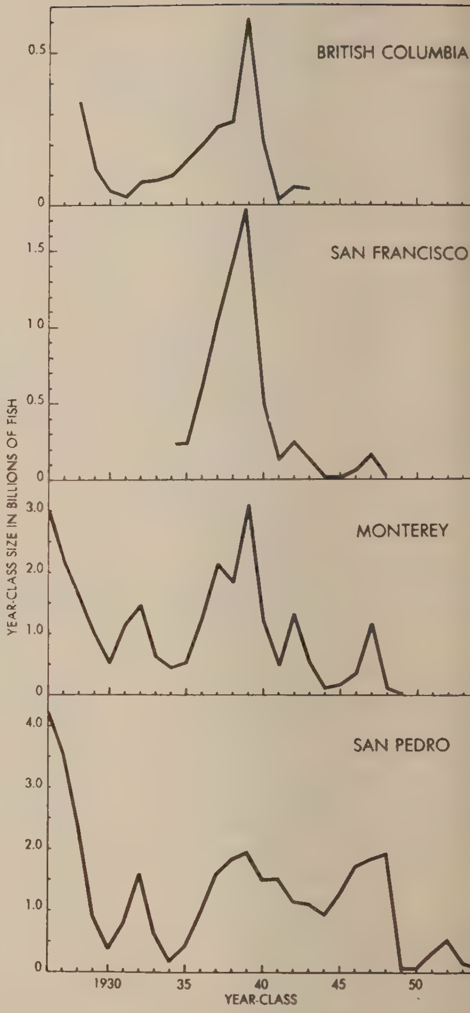
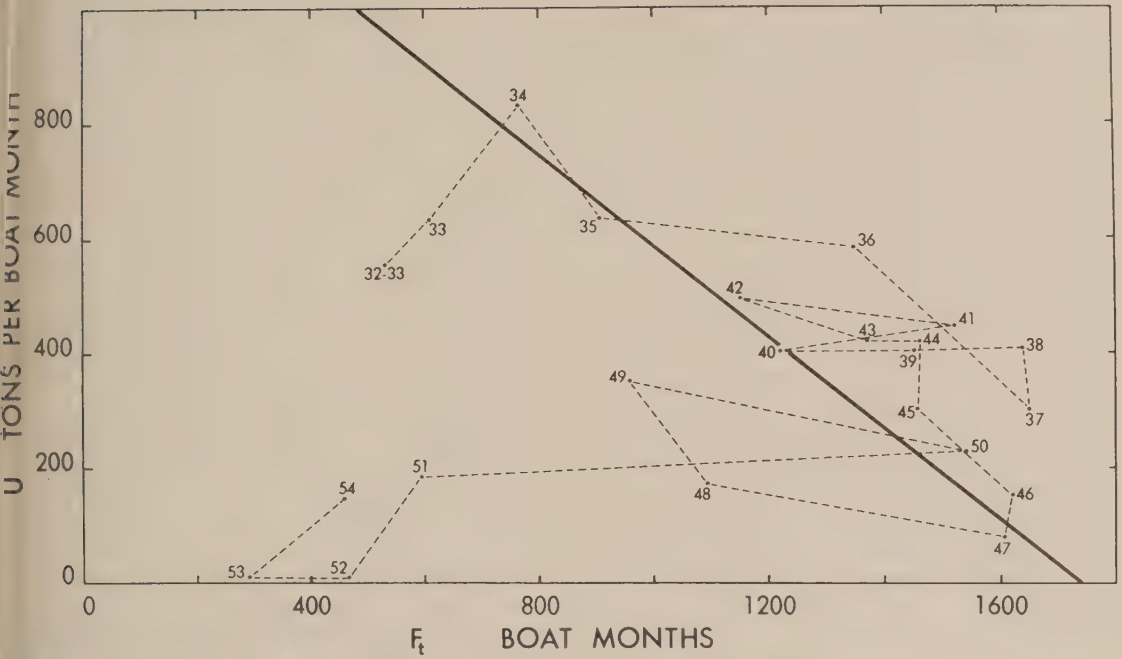


Figure 7. Accumulated age estimates of sardine year-class s
at British Columbia, San Francisco, Monterey and San

function of stock size was at some (unknown) le
than any observed spawning stock size.

In addition, although it is postulated that spa
has been unsuccessful on the southern Cal
spawning grounds since 1943, this can not be a
ted to lack of spawning in the area. There was s
ing between 1949 and 1951, and between 195
1957; spawning was negligible in the area in
and 1953. But in 1956, it has been estimate
about $1{\cdot}8 \times 10^9$ fish spawned on the southern Cal
spawning grounds.

Other attempts to explain variations in s
population size have apparently involved the
assumption that these are density independent a



ure 8. Extension through 1954–55 season of SCHAEFER's (1954:53) plot of "Relationship between intensity of fishing and mean population, California sardine".

use has been sought in the environment. WALFORD 946) proposed a relationship between salinity, as a easure of upwelling, and year-class strength on the sis of a high positive correlation over the period 34–41. Data for the period 1942–55 show a negative sociation (see Figure 9). Although I believe the sociation he observed is related to certain features my model, the particular model he proposed has th logical and practical objections.

More recently, SETTE (1960) postulated that the quisites for the production of large sardine year-asses include (1) the opportunity for spawning rough a considerable period of time, as evidenced y relatively high surface temperatures and (2) the ntensification of the southern California eddy such at the larvae are eventually carried inshore. Further, e suggested that in years of above-average north-esterly winds, surface temperatures are lower, the ddy is less well developed and, as a consequence, ear-class strength, on the average, is small. Conersely, in years of below-average north-westerly inds, surface temperatures are higher, the eddy is ell developed and year-class strength, on the average, s large.

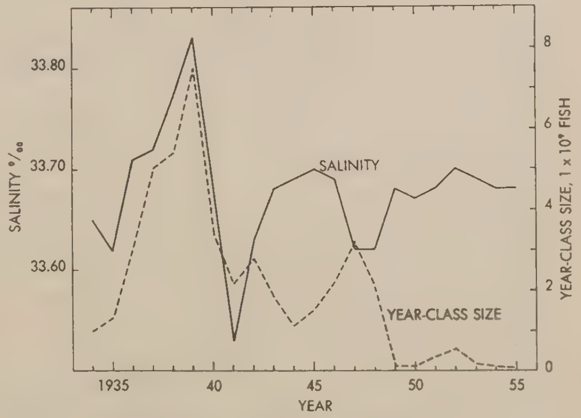


Figure 9. Average surface salinity at Scripps' Pier (June to August) and accumulated age estimates of sardine year-class strength.

According to this model, the observed conditions ere such that the southern California eddy should ave been poorly developed in 1955 and 1956 and well developed in 1958. However, the returns from drift bottles released on three station lines off southern California, more or less normal to the course of the eddy, show no consistent differences among these years (see Figure 10). Again, it appears that this proposal is related to certain features of my model.

If, then, the decline in sardine catch and population size are density independent, how does the environ-

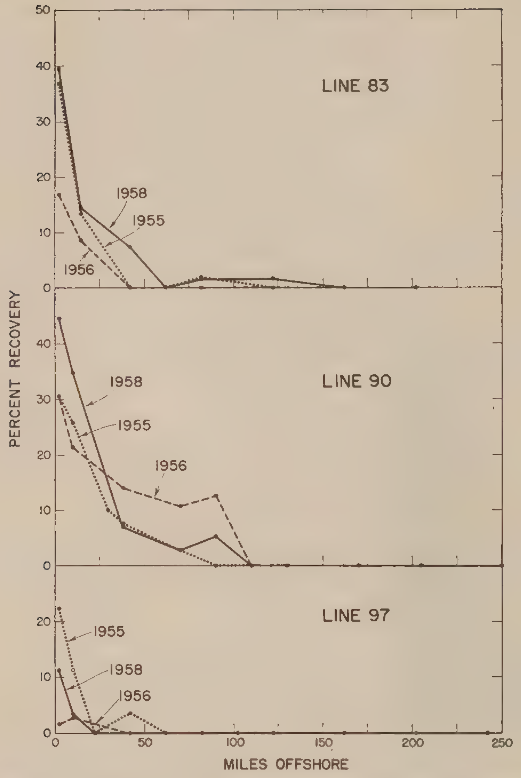


Figure 10. Recoveries of drift bottles, as a function of distance offshore of point of release, released off southern California in 1955, 1956 and 1958.

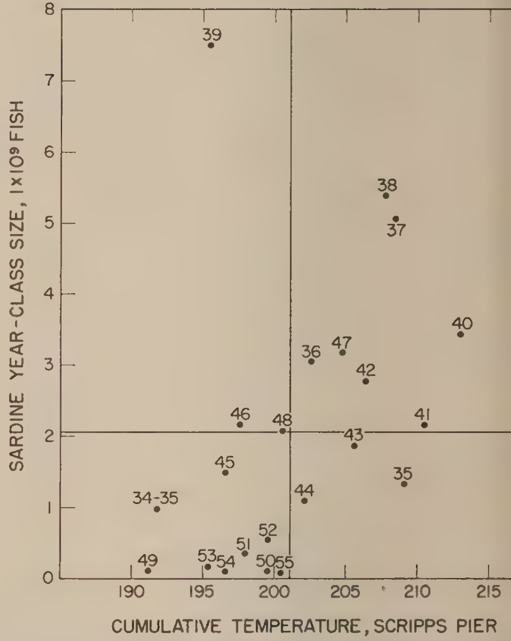
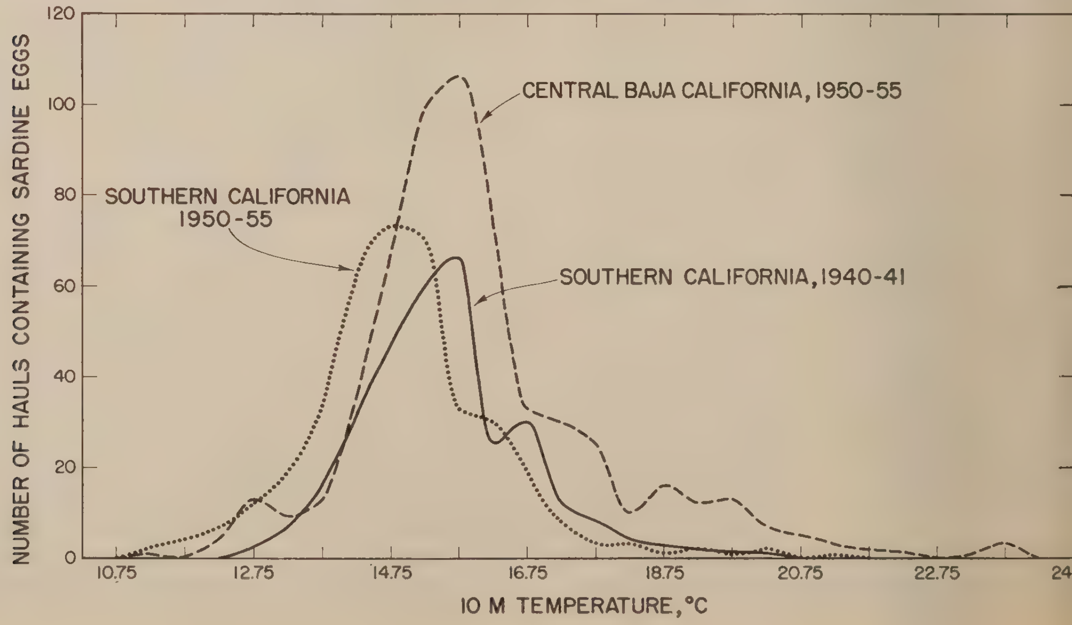


Figure 12. Relationship between sardine year-class size measure of annual cumulative temperature (sums of means, April to March) at Scripps' Pier.

Figure 11. Frequency distribution of plankton hauls con sardine eggs at the temperatures at which they were taken area off southern California in 1940–41 and 1950–55 and t off central Baja California in 1950–55.



not act to control population (year-class) size? The surface temperatures off southern California were lower from about 1944 to 1957 than they were in the period prior to 1944 or than they have been in recent years. As a consequence, sardine spawning off southern California has been at lower than normal temperatures (see Figure 11) and also later in the year.

ince sardines are poikilothermous animals, it is obvious that gonad maturation, and hence spawning time, must be strongly influenced by the annual temperature regime, as well as by other factors, including solar radiation and quality and quantity of food. If the annual temperature regime falls below a threshold value, one might expect that spawning would be delayed to such an extent that the eggs and larvae would be out of phase with their normal environment and the production of a successful year-class would be impossible or, at least, unlikely. On the other hand, if the annual temperature regime is adequate, the production of a successful year-class might or might not occur, depending upon other factors. In other words, an adequate temperature regime is a necessary condition, but not a guarantee.

If, then, year-class strengths were plotted against measures of the annual temperature regime and quadrants were formed by lines, parallel to the axes, passing through (a) the average year-class size and (b) the temperature threshold: all successful year-classes should l in the upper right quadrant, while unsuccessful ar-classes should be found in both the lower right d lower left quadrants. No year-classes should fall the upper left quadrant.

Estimates of sardine year-class strength may be otted against a measure of cumulative temperature rresponding to the normal spawning cycle (April to arch) and the quadrants formed appropriately. The reshold temperature value appears to be at about 1 units (see Figure 12). The points conform to expectation with the exception of that for the 1939-class. spite of this anomalous point, I am inclined to cept this approach, since 1939 was an anomalous ear in at least two respects.

If there is, then, a general relationship between the mperature regime and spawning success and if this lationship operates by imposing a delay in spawning me, how does this specifically affect the sardine? suggest that the temperature imposed delay places he sardine larvae at a disadvantage with respect to ne of their major competitors, the northern anchovy *Engraulis mordax*). This follows because (a) the spawning areas of the two species overlap to a large extent n space and time, (b) they eat the same food items, the threshold and peak spawning temperature of he anchovy are both about 2° C lower than those of he sardine, and (d) anchovy larvae abundance off southern California has been about twice as great in 1953–56, a cold period, as it was in 1941, a warm year, and, relative to sardine larvae abundance, the increase has been even more marked.

Finally, the apparent differences between my model and those of Walford and Sette may be reconciled by knowledge of the oceanography of the southern California region. *Low* temperatures and *high* salinities occur under conditions of above-average NW winds, which act to intensify the California current system (south-easterly flow of water) and coastal upwelling. *High* temperatures and *high* salinities occur under conditions of below-average NW winds, which act to relax the California current system and permit the advection of offshore and/or southerly water into the southern California region. Thus, although high salinities are associated with the requisite conditions for successful year-classes (Walford's model), these are due to advection rather than upwelling. And although below-average NW winds are also associated with the requisite conditions for successful year-classes (Sette's model), this appears to represent an advection process rather than an intensification of the southern California eddy.

Model formation: the importance of subpopulation identification

The process by which we obtain ideas, insight, intuition, or whatever you may wish to call it – that process of communication from the subconscious to the conscious level of thought – is not well understood. Indeed, Dewey (1933), as paraphrased by Beveridge (1953: 73), has said "... that the conjuring up of the idea is not a deliberate, voluntary act. It is something that happens to us rather than something we do."

While it is not pertinent to consider this general problem, I have given some thought, in retrospect, to the circumstances which made it possible for me to erect a model of sardine population biology. (The question of whether or not my model has verisimilitude is probably not pertinent to this particular point.) I believe the following were of major inportance: –

(a) There existed a large body of information about the sardine and its environment.

(b) An attempt was made to examine all available data (not just a particular fraction) under the requirement that they had to be explained by a model or at least be consonant with it.

(c) There was strong reason to suspect, on the basis of the distribution of spawning, the existence of more than one subpopulation.

(d) There had just occurred a striking change in the environment after a fairly long and monotonous period.

(e) I was working against a deadline to summarize what was known of the sardine and to explain, if possible, the decline. (The importance of this circumstance may only be a reflection of personal work habits.)

Leaving aside (e) as a personal circumstance and (a) as a general requisite, I would categorize the other circumstances as follows: (b) was an essential frame of reference; (c) was the concept which made the model possible; and (d) was the spark which ignited a train of thought.

Although the concept of categories of less than subspecific rank is one of the oldest in fishery biology, I should like, in conclusion, to emphasize the importance of subpopulation identification. By subpopulation, I mean a genetically self-sustaining unit. During the period of my work on the sardine, it was abundantly clear, from the distribution of spawning, that there was opportunity for genetic isolation. It was not clear, however, whether this opportunity was realized or if certain characteristics of the fish were merely imposed upon them by the environment as the result where they happened to have been spawned. Lacking information to the contrary, I leaned for some time to the latter view. It is of great interest to note the subsequent results of Sprague and Vrooman (1962), who, on the basis of the study of blood group characteristics, have been able to identify at least two genetically distinct population units; a northern and a southern subpopulation.

Although the concept of infra-specific groups is not new, I believe that the importance of identifying such groups on a genetic basis, and the power of such identification, have not been fully appreciated. Marr and Sprague (1961) have recently discussed, at least in part, this problem.

Summary

It is proposed that the decline in sardine landings along the Pacific coast of North America resulted from a decline in population size; that population
was reduced because of a relatively long series of s
year-classes; and that this series of small year-cla
resulted from an unfavourable oceanographic regi
rather than a reduction in the size of the spaw
population.

The proposed model is compared with the avail
data and with previously proposed models.

It is suggested that the unfavourable environ
(reduced temperatures) is mediated through c
petition with the northern anchovy.

The existence of two independent subpopulat
is a key feature of the model. The importance of s
population identification is emphasized.

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50.

The Use of Blood Group Characteristics in Studying Subpopulations of Fishes

By

JOHN C. MARR* and LUCIAN M. SPRAGUE*

Introduction

"It is one thing to recognize the existence of racial diversity and another to define it in terms of the underlying genetic facts." (Stern, 1960, p. 681).

The necessity of identifying population units** within species of fishes that are the objects of commercial fisheries has long been recognized and has recently been summarized by Mužinić and Marr (1960) as:

"The logical and practical reason for identifying population units is that such units may have their own characteristics of recruitment, growth, natural mortality, migration, behavior, etc., more or less independent of the characteristics of other population units within the same species. The need for studies of population units in a particular situation may arise from two sources: (a) There exist variations in yield and/or heterogeneities in the characteristics of the catch for which the most likely explanation (hypothesis) is the existence of population units. (b) Management decisions have been made empirically for which it is necessary or desirable to provide understanding and thus confidence in the original decisions."

Methods of studying subpopulations have recently been reviewed (Marr, 1957) and may be grouped in four categories, according to the characteristics studied. These include (1) phenotypic qualities, (2) movements as revealed by tagging or marking, (3) vital statistics and (4) genetic characteristics. Studies of phenotypic qualities (meristic and morphometric characteristics) and of movements revealed by tagging are too well known to require examples. The concept of identifying population units on the basis of vital statistics (rates of recruitment, death and growth) has only recently been proposed by Holt (as reported by Mužinić and Marr, 1960). The use of genetic characteristics, especially blood groups, is also a recent innovation.

The use of phenotypic characteristics has a number of limitations. The characteristics used are frequently of the form of overlapping frequency distributions and, even with the more sophisticated techniques recently employed (see Royce, 1957 and MS, example), show (1) that the samples were not dra from the identical universe and (2) the maxim possible mixing. Moreover, since the characterist are susceptible of environmental modifications, observed differences may relate to environme rather than to subpopulations. Frequently, if generally, the samples are not drawn from spawn assemblages, so that real mixtures of subpopulati could remain undetected.

Tagging experiments require that fish be tagg and returned. This is not only costly in time a effort, but effectively limits such experiments areas in which there is an effective recapture mec nism (i.e., a fishery). Again, the tagging experim is generally not performed on spawning asse blages, so that the question of interest is exami with less than maximum precision.

The use of vital statistics may, in fact, correspo more nearly to a definition of a subpopulation rat than to a tool for studying subpopulations. Th utility as a tool would be increased if they could applied to spawning assemblages.

The limitations and advantages accruing from use of blood groups in studying subpopulations considered in greater detail below. But a mi semantic difficulty must first be noted. The phenoty characteristics referred to above are genoty characteristics as modified by the environment; t are plastic. Numbers of vertebrae are an example such a plastic phenotypic characteristic. Ma quantitative genetic traits are subject to such vironmental modification. There are also phenoty characteristics which are not susceptible of envir mental modification and bear a direct relations to the genotype; they are non-plastic. Many qualitat genetic traits have direct, regular genotype-phenoty relationships. Blood group phenotypes belong to latter, non-plastic category.

Blood Group Systems

Blood groups are studied through the use of antigen-antibody reaction. A number of compou on or in the erythrocyte surface, and the solu specific substances (A of man, for example), consti blood group substances. These substances are f quently present in certain individuals and lacking

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** A population unit may be defined as a fraction of a population that is itself self-sustaining. This is identical with the definition of subpopulation given by Marr (1957). Population unit, subpopulation and interbreeding population are here considered to be exact synonyms and are used interchangeably throughout.

hers. The substances are probably polysaccharides d are certainly antigens*.

Erythrocyte antigens and soluble specific substances ave been found to be under genetic control in ery animal in which this question has been studied. he various antigens which occur separately, or gether, in response to the segregation of genetic aterial at a single locus or genetic site, constitute a lood group system. Thus, antigens which are not enetically related belong to different blood group stems.

Antibodies, a constituent of plasma, occur either aturally or as products of the immune mechanism. ntibodies are reasonably antigen-specific and react n demonstrable ways with the appropriate antigen. he simplest and most common method of observing he reaction of antibody and erythrocyte antigen is he agglutination reaction. Thus, anti-x serum can e used to classify red blood cells according to the resence or absence of x (antigen). Initially, the nvestigator must acquire a set of antisera or reagents hat will identify one or more of the blood groups resent in the species of interest. Such reagents may e developed by the introduction of red blood cells f the species being studied into other individuals of the same species, into individuals of other species or, more rarely, they may occur naturally in the same or other species. It has been found (Mäkelä, 1957; Bird, 1959) that extracts of the seeds of many legumes are very useful in this regard. The exact nature of the "antibodies" in the legume seeds is not known, but they are proteins, probably globulins (Boyd et al., 1958).

Exploratory classification of samples of the species under study will proceed, of course, simultaneously with the development of antisera. At some point the investigator will be satisfied that the antisera can identify one or more blood groups and will begin to examine series of samples from appropriate localities. Since erythrocytes are frequently difficult to preserve for any length of time, this may mean quite literally taking the tests to sea.

With this technique, samples of a subpopulation are not ordinarily classified according to the presence or absence of a single characteristic, although this could be the case. In fact, most blood group systems are genetically quite complex, having more than two alleles; 6—9 alleles are not uncommon, and one blood group system in cattle has more than one hundred and fifty**. It follows, then that samples are classified according to the frequency of presence or absence of several characteristics. Thus, in comparing samples, there still exists the problem (which fishery biologists constantly encounter) of making sample-size adequate to enable distinction between observational error and real differences between samples. But it should be borne in mind that the differences, if any, relate to non-plastic rather than plastic phenotypes.

There is a further quality of genetic characteristics which adds great power to the use of this tool. In the presence of random mating***, and assuming no mutation or selection effects, the frequencies of alleles p, q . . . x will occur in proportions according to the expansion of the binomial. This condition will obtain after only one generation of random mating and will persist thereafter. This general concept is known as the Hardy-Weinberg Law. It follows, then, that single samples can be examined to determine whether or not they conform to this law. If a sample does not conform to the Hardy-Weinberg Law, it may be concluded that it was not drawn from an interbreeding population; i.e., it was composed of individuals of two or more interbreeding populations. If a sample does conform to the Hardy-Weinberg Law, the data are consonant with the hypothesis and it may be concluded that the sample was drawn from an interbreeding population.

Some Examples

Examples may be drawn from observed frequencies of the phenotypes (and, in this case, the genotypes) of the M-N blood group system in humans (Stern, 1960). The mode of inheritance is that of two alleles, $\underline{L}^M$ and $\underline{L}^N$, and the phenotypes, M, MN and N can all be identified serologically. Data on the observed frequencies of these phenotypes in seven populations, the computed allele frequencies and the expected phenotype frequencies are given in Table 1. The frequency of allele $\underline{L}^M$, $p\underline{L}^M$, is computed from

$$p\underline{L}^M = \frac{\overline{M} + {}^1/_2\,\overline{MN}}{100},$$

and $q\underline{L}^N$ from

$$q\underline{L}^N = 1 - p\underline{L}^M,$$

where $\overline{M}$ and $\overline{MN}$ are the observed relative frequencies (percentages) in the populations.

The samples of the first six populations all conform closely to the Hardy-Weinberg Law and each may be considered to have been drawn from a distinct interbreeding unit or subpopulation. The seventh sample, however, does not conform to the Hardy-Weinberg Law and could not have been drawn from a distinct subpopulation ($P < 0.01$). The data were in fact obtained by combining, in equal parts, data from the first (Caucasian) and fourth (Eskimo) samples.

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* Certain soluble-specific substances found in the body fluids might be considered to be non-antigenic.

** It should be pointed out that, lacking genetic information, the recognition of a particular blood group system as a 2, 3, 4 or x allele system is an assumption.

*** Random mating refers not to random mating between individuals, but rather to random combinations within a gene system.

Table 1

Frequencies of M—N blood types in different human populations. Slightly modified from Tables 17 and 18 of Stern (1960)

N	Population		Percentages of Blood Types M	MN	N	Allele Frequencies $p\underline{L}^M$	$q\underline{L}^N$
6129	Caucasian	obs.	29.16	49.58	21.26	0.540	0.460
	(U.S)	exp.	29.16	49.68	21.16	—	—
278	Negro	obs.	28.42	49.64	21.94	0.532	0.468
	(U.S.)	exp.	28.35	49.89	21.86	—	—
205	Indian	obs.	60.00	35.12	4.88	0.776	0.224
	(U.S.)	exp.	60.15	34.81	5.04	—	—
569	Eskimo	obs.	83.48	15.64	0.88	0.913	0.087
	(E. Greenland)	exp.	83.35	15.89	0.76	—	—
504	Ainu	obs.	17.86	50.20	31.94	0.430	0.570
	(Japan)	exp.	18.45	49.01	32.34	—	—
730	Aborigine	obs.	3.00	29.6	67.4	0.178	0.882
	(Australia)	exp.	3.17	29.26	67.57	—	—
1000	X	obs.	56	33	11	0.725	0.275
		exp.	52.3	39.9	7.6	—	—

Another example that may represent a two-allele system has been given by Sinderman and Mairs (1959). They were able to classify individual herring in the Gulf of Maine as either C-positive or C-negative. Samples from different localities were characterized according to percent C-positive and those from the northeastern Gulf were found to have a higher percentage (about 98%) of C-positive fish than samples from the southwestern Gulf (about 77%). If this is a regular two-allele system, the genotypes $\underline{CC}$ and $\underline{Cc}$ are classified as C-positive and $\underline{cc}$ as C-negative. Lacking the ability to distinguish between $\underline{CC}$ and $\underline{Cc}$ individuals, it is not possible to determine if these samples conform to the Hardy-Weinberg Law. The possibility exists that this C system is actually a much more complicated system, consisting of $\underline{C_1}$, $\underline{C_2}$, $\underline{C_3}$ ... $\underline{C_x}$ alleles. If this is so, the genotype $\underline{C_xC_x}$ is identified as being C-negative; the remaining genotypic combinations are C-positive. This is a common genetic problem and its significance is only one of the degree to which phenotypes may be regularly related to allelic combinations.

Similarly, Sprague and Vrooman (MS) have discovered a C system* in the sardine of the northeastern Pacific. Although this is believed to be multiple allele system and is known to be a multip antigen system, the individual fish were classified on as C-positive or C-negative. Otherwise, the gener remarks about the C system in herring apply her

A two-allele system, $\underline{A}$-$\underline{a}$, has been report in sockeye salmon by Ridgway, Cushing and Dur (1958, 1961). It is possible to recognize all thr phenotypes. Although the results presented a preliminary (and based upon relatively small sample the samples from two spawning tributaries of t Columbia River conformed to the Hardy-Weinbe Law, whereas samples from (1) the main Columb River and (2) rivers from Kodiak Island to t Fraser River (combined) did not. The latter tv samples, of course, would be expected, on the ba of other information, to be composed of individu from several spawning populations. A fifth samp from rivers tributary to Bristol Bay (combined) d conform to the Hardy-Weinberg Law. It would expected that this sample consisted of individuals fro several spawning populations, and Dr. Ridgway h informed us (personal communication) that addition studies indicate the existence of distinct populatio within one of the rivers tributary to Bristol Bay. T original conclusion of homegeneity within the rive tributary to Bristol Bay is thus modified.

A blood group system designated Tg1—Tg2— has been found in albacore tuna by Suzuki, Mo and Mimoto (1959). We interpret their data indicate a blood group system with three allel analogous to the human A-B-O blood group syste Suzuki et al. (1959) give data for samples from t Pacific Ocean in the general area southeast of Hons and from the Indian Ocean largely from the gener area southwest of Sunda Strait. The striking differenc between samples from these two areas in phenoty frequencies were noted, but the question of wheth or not the samples from each area were drawn fro an interbreeding population was not examined. It of interest to do so.

According to the Hardy-Weinberg Law, if t samples were drawn from an interbreeding populatio then the following relationship obtains:

$$\underline{Tg1} + \underline{Tg2} + \underline{0} = 1$$

where

$$\underline{Tg1} = 1 - \sqrt{\overline{0} + \overline{Tg2}},$$

$$\underline{Tg2} = 1 - \sqrt{\overline{0} + \overline{Tg1}}$$

and

$$0 = \sqrt{\overline{0}}\,.$$

Substituting the Pacific Ocean data

$$0.04 + 0.71 + 0.27 = 1.02\,.$$

---

[*] The use of the same letter to designate blood group systems in different species does not indicate, barring a specific statement to the contrary, the existence of the identical or even similar blood group in the different animals. This practice arises because of the small number of letters in the alphabet and the tendency to use the earlier letters of the alphabet.

the Indian Ocean data, however

$$0.39 + 0.55 + 0.30 = 1.24 .$$

s, it may be concluded that the Pacific Ocean ples were drawn from a single interbreeding ulation, but that the Indian Ocean samples were vn from a mixture of two or more interbreeding ulations. There is, incidentally, other evidence m tagging experiments, for example) that the .core of the North Pacific constitute a single rbreeding population. A similar inference (based much less evidence) is possible about albacore of South Pacific.

nother three-allele A-B-O analog, termed $\underline{S}_1$-$\underline{S}_2$-$\underline{S}_0$, been reported in the spiny dogfish in the Gulf Maine by Sinderman and Mairs (1961)*. Their a conform to the Hardy-Weinberg Law, indicating their samples were drawn from a single inter- eding population. An interesting aspect of their k was the comparison of the blood group types pregnant females and their unborn pups. The ılts of this comparison were consonant with a e-allele system.

final example is that of the sardine B system rague and Vrooman, MS), which by detailed logical analysis suggests a system in which at t four alleles are segregating. In practice, it was sible to recognize only three phenotypes and one hem occurred so rarely (0.001) as to be negligible. s particular system affords a good example of the iculties which may be encountered in working h complicated blood group systems. The work of ague and Vrooman (MS) is also of interest in that C system (see above) and the B system were wn to be independent.

Ve have not considered the statistical methodology tinent to these problems. Reference to three vious works may be helpful. Applications of χ^2 e been given by Race and Sanger (1958). An roduction to the methods of gene frequency culations and the application of χ^2 has been sented by Mourant (1954). In cases where χ^2 is pertinent, the Z test for the significance of the ference between proportions and the t test for significance of the difference between means are ful (see, for example, Freund et al., 1960).

Application to Fishery Problems

On a practical basis, the general "subpopulation blem" in fishery biology involves (1) the definition d recognition of the interbreeding unit and (2) the delineation of its geographic range, including its spawning range and its total range.

This general problem is usually encountered in more specific form, and hypothetical examples of three common situations will be considered. (While the examples given above on the occurrence of blood group systems in fishes are pertinent, data on human blood group systems will be used illustratively only because they are much more extensive and not because of any inherent superiority.)

First, are the fish at Area A (which is, say, the area of a fishery) from a single subpopulation or from more than one? Each of the first six samples in Table 1 may be considered to be analogous to fish samples drawn from six Area A's. On the basis of the MN blood group, it may be said that each of these samples represents an interbreeding population. The seventh sample, however, does not conform to Mendelian expectations and must represent individuals from two or more subpopulations. This examination of the data will not indicate how many populations are involved, although it may be recalled that these particular data were made by equal contributions from two of the other groups in the table.

In the case where heterogeneity is found, the subsequent steps taken to determine exactly how many populations are involved and their distributions are difficult to generalize, since they will be determined by the real situation obtaining and how much the investigator knows about it.

Second, are the fish from discrete Areas B and C, which are both fishery areas, of the same population or of distinct subpopulations? As an example, consider the data of Table 1 for Eskimo and Aborigine. These have each been demonstrated to represent an interbreeding population. They are so different it is obvious that they represent two distinct populations, rather than two samples of a single population.

But suppose that, instead of Eskimo and Aborigine, samples from the two areas were represented by Caucasian and Negro. It is obviously impossible to distinguish between these two population units on the basis of the M-N blood group system. However, an additional set of allele frequency estimates (Table 2) for a genetically independent blood group system, the A-B-O system, demonstrates that these two samples are, in fact, from distinct population units ($P < 0.01$). (If these A-B-O data were pooled, representing a single sample drawn from a single area, as in the first hypothetical example, it would only have been possible to conclude that two or more subpopulations were present. The exact number could not have been specified without additional data.)

This particular example emphasizes the obvious: The greater the number of genetically independent blood group systems by which the organisms may be classified, the more powerful will be the method.

---

* The use of subscripts in the designation of the antigens of spiny dogfish and of the albacore is probably unfortunate, e there is a conflict in this terminology with the accepted ation for regular subtyping relationships such as are found in A_1, A_2 series of the A-B-O blood group.

Third, if fish from discrete Areas D and E, which are nonfishery areas, are known to be separate subpopulations and if fish from these separate areas (subpopulations) mingle in Area F, which is a fishery area, what is the relative contribution of each subpopulation to the fishery area? An example is found in Table 1, if the Caucasian data are considered to represent Area D, the Eskimo data Area E and the X data Area F. This is a straightforward problem, since there is a unique combination of the observed blood group frequencies in Areas D and E which will yield those observed in Area F.

Table 2

Frequencies of A—B—O blood groups in two human populations comparable to those represented in Table 1. From Boyd (1939)

N	Population	Percentage of blood types				Allele frequencies		
		O	A	B	AB	pI^{A}	qI^{B}	rI^{O}
500	Negro (U.S.)	47.0	28.0	20.0	5.0	0.181	0.133	0.686
1708	Caucasian (U.S.)	44.0	37.9	13.2	4.5	0.240	0.094	0.668

Advantages and Disadvantages

The advantages and disadvantages of the use of blood group systems in the study of subpopulations of fishes may be summarized. Advantages:

1. The characteristics studied are genetic.
2. Not only can samples be compared, but single samples can be examined with respect to whether or not they were drawn from a single subpopulation.
3. The statistical procedures involved are simple.
4. Recaptures are not required (i.e. there need not be a fishery).

Disadvantages:

1. Blood preservation may be a problem. If it is, the method must be taken to sea.
2. Developing reagents may be difficult and time-consuming.
3. For the full power of the technique to be realized, blood group systems must be identified and it must be possible to recognize one more phenotype than the number of recognized alleles. (This provides the degree of freedom necessary for Hardy-Weinberg analysis.)

It is apparent to us, and, we hope, to others that the use of blood group systems in fishes constitutes an extremely useful and powerful tool in the solution of problems involving the definition and recognition of interbreeding populations. Examples of such problems have been given above. It also seems to us that, in the long run, the use of this tool will lead to m important results in the understanding of populati of fishes in nature, especially in three areas; (1) t genetics (in the classical sense) of fishes; (2) t interaction of fish and environment leading isolation of population units and the nature of th isolating mechanisms; and (3) population genetics.

Summary

The necessity for studying population units fishes, the desirability of using genetic characteris in such studies, and the nature of blood group syste are briefly reviewed.

Examples are drawn from M-N and A-B-O blo groups in man. Examples are given of blood gro systems recently found in several bony fishes, cluding western Atlantic herring, northeastern Pac sardine, sockeye salmon, albacore tuna, and also one elasmobranch, the spiny dogfish.

Illustrations are given of how data on blood gro systems are useful in attacking the kinds of proble encountered by fishery biologists. It is suggested t such data will also contribute to the solution broader problems.

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INFLUENCE OF MINERAL COMPOSITION OF NATURAL WATERS ON STRONTIUM ACCUMULATION AND DISCRIMINATION BY FRESHWATER PHYTOPLANKTON.

J. S. Marshall and A. M. Beeton, University of Michigan and U. S. Bureau of Commercial Fisheries.

The influence and relative importance of the different major ions in natural waters on the strontium concentration factor, $Sr_{(org)}$ $Sr_{(env)}$, and the observed ratio, $(Sr\ Ca)_{org}$: $(Sr\ Ca)_{env}$, in freshwater phytoplankton are currently being studied. Results are reported on preliminary experiments in which suspensions of *Chlamydomonas reinhardi* cells are allowed to equilibrate (in constant darkness) with different natural waters which were membrane-filtered, chemically analyzed, and doubly labeled with the radioactive tracers Sr^{85} and Ca^{45} prior to adding the test algae. After reaching equilibrium, the Sr^{85} and Ca^{45} taken up by the algae are determined by radioassay of dry, membrane-filtered samples in scintillation and GM counters respectively. Natural waters for use in future experiments have been collected from diverse types of lakes and streams in and around the state of Michigan (including four of the Great Lakes: Superior, Michigan, Huron, and Erie).

Other experiments are in progress which are designed to determine the relative importance of assimilation and adsorption in the uptake of strontium.

Reprint from Proceedings of Sixth Conference on Great Lakes Research, 1963.

Made in United States of America
Reprinted from Copeia, 1963, No. 2, June 14
pp. 460–462

Unique Shape of the First Elongate Haemal Spine of Albacore, *Thunnus alalunga* (Bonnaterre)

Walter M. Matsumoto

UNIQUE SHAPE OF THE FIRST ELONGATE HAEMAL SPINE OF ALBACORE, *THUNNUS ALALUNGA* (BONNATERRE).—There have been numerous studies of the internal organs and skeletal parts of the tunas. It seems surprising that although many of these anatomical studies have dealt with minute details, none has ever pointed out the striking appearance of the first elongate haemal spine (the haemal spine of the first caudal vertebra) of the albacore, *Thunnus alalunga* (Bonnaterre). Where the main body of this spine flexes sharply caudad, a short branch appears to continue ventrad at about the same angle as the proximal part of the spine. The triangular space between this branch and the main spine is filled by a web of bone so flattened and thin as to be translucent. Kishinouye (1923, *J. Coll. Agric., Tokyo 8[3]:293–475*) depicted this bone accurately in his illustration of the albacore skeleton, but he did not discuss its peculiar form in the text.

Yabe *et al.* (1958, *Rep. Nankai Reg. Fish. Lab. 8:31–48*) first used this character in identifying tuna skeletal material collected in the Pacific from the stomachs of pelagic fishes which often prey on young scombroids. They illustrated the haemal spine from a 25.8-cm juvenile and compared its structure in adults and young but did not present any supporting data to show the reliability of this character.

The present paper reports evidence that among the tunas the extremely flattened and enlarged haemal spine on the first caudal vertebra is found only in the albacore and its occurrence is consistent within that species. The nomenclature used in this report follows Collette (1962, *U. S. Fish Wild. Serv. Spec. Sci. Rep. 415:1–24*). Thus, *Thunnus thynnus* (Linnaeus), *T. alalunga* (Bonnaterre), *T. albacares* (Bonnaterre), *T. obesus* (Lowe), *T. atlanticus* (Lesson), and *T. tonggol* (Bleeker) represent bluefin, albacore, yellowfin, bigeye, blackfin, and longtail tunas, respectively. For this study the first elongate haemal spines of 492 *T. alalunga* (80–115 cm F.L.), 337 *T. albacares* (64–169 cm F.L.), and 251 *T. obesus* (105–173 cm F.L.) were collected from several sources: the Honolulu fish market, the Hawaiian Tuna Packers cannery, and two cruises of the Bureau of Commercial Fisheries' research vessel CHARLES H. GILBERT.

A distinct flatness of this spine was se in all *T. alalunga* but in none of the *albacares* and *T. obesus* examined. Gen ally, the flattened section began at abo the middle of the spine and included abo ¼ to slightly less than ½ the total length the spine (Fig. 1A). There were some va ations in the shape, and while the inciden of such variations was negligible, the diff ences in form were quite remarkable. the most extreme example of flattening c served, the distal part of the spine appear to be displaced posteriorly until it nea touched the next haemal spine, and the d tal and proximal portions were connect only by a long, translucent plate of bo An example of the minimal development this character is given in Figure 1B. T flat portion in this specimen is not ve wide, but it is still about 3 times wider th the portion proximal to it, and the char teristic flatness is unmistakable, even wi out direct comparison with the spines other species. With few exceptions, t width of the first caudal spine varied fr twice the width of the example in Figu 1B to slightly less than that shown in Figu 1A. Over 90 per cent of all the spines amined fell into this range. The seco elongate haemal spine (the haemal spine the second caudal vertebra) of *T. alalun* also shows some tendency to flatness, b the extent of the flattening varied cons erably among my specimens.

Of the other two species examined, t first elongate haemal spine of *T. obe* shows a slightly greater tendency towa flatness than that of *T. albacares*, but t width of the flat portion is not quite tw the width of the narrowest part proximal it (Figs. 1C and 1D). Moreover, the natu of the flat section differs markedly fr that of *T. alalunga*: in *T. alalunga* it very thin and somewhat translucent, wher in *T. obesus* and *T. albacares* it is qu thick and strong. In the latter two spec there is very little, if any, variation in t width of the spine, and the second elong haemal spine of these two species, unli that of *T. alalunga*, does not exhibit a tendency towards flatness.

Bruce B. Collette of the Bureau of Co mercial Fisheries Ichthyological Laborat has informed me that X-ray plates which made of 12 *T. tonggol* and 1 *T. atlanti* show that the shape of the first haem

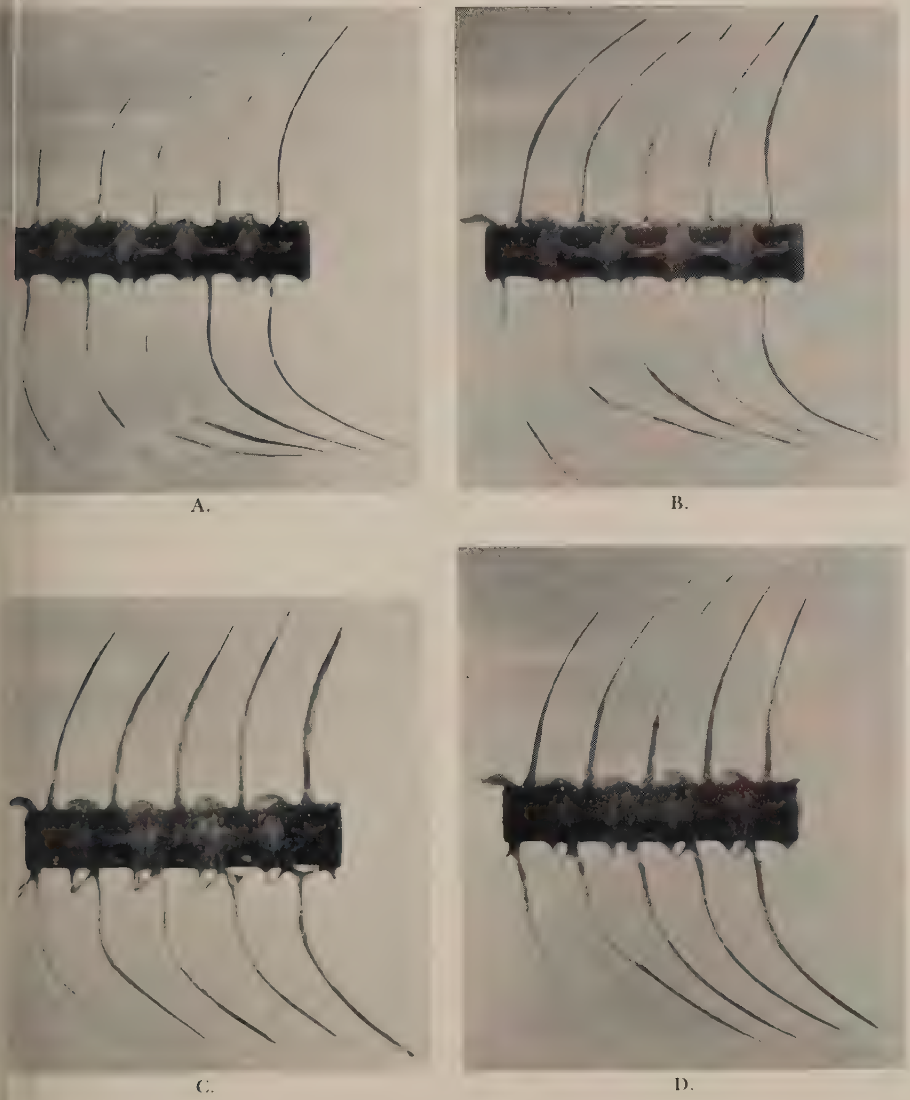


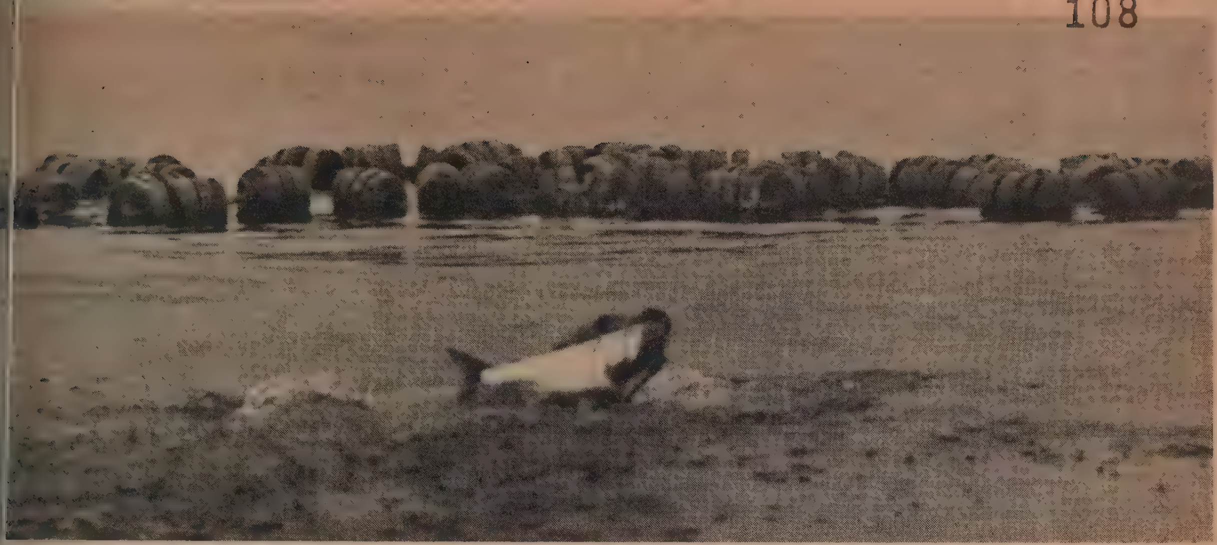
Fig. 1. First elongate haemal spine: A. *T. alalunga* (104 cm F.L.); B. *T. alalunga*, showing inimal development; C. *T. albacares* (106 cm F.L.); D. *T. obesus* (105 cm F.L.).

ine in those species is similar to that of *albacares*. These observations agree with blished figures of *T. tonggol* in Kishiuye (1923) and of *T. atlanticus* in De lva (1955, *Bull. Mar. Sci. Gulf Caribb.*]:*1–41*). The corresponding spines of *T. ynnus* from Australia, California, and the estern Atlantic Ocean figured by Godsil d Holmberg (1950, *Fish Bull., Calif. Fish ame 77:1–55*) and from the western Pacific Ocean (Kishinouye, 1923) resemble those of *T. albacares* and *T. obesus*. Robert H. Gibbs, Jr. (personal communication) has also observed that the spine is not flattened in *T. atlanticus* and *T. thynnus* of the Atlantic Ocean.

It appears, therefore, that *T. alalunga* is the only known species of *Thunnus* which possesses an enlarged, flat haemal spine on the first caudal vertebra.

This character will be of value to those who have occasion to identify young *T. alalunga* which are taken, often digested beyond recognition, from the stomachs of large predators. The character is also useful in identifying the juveniles smaller than 10.0 cm which are sometimes caught by night-lighting. Recently, during an examination of contents of tuna and marlin stomachs collected on CHARLES H. GILBERT Cruise 55 in the southwest Pacific, two juvenile tuna were found, approximately 6.2 and 7.4 cm S.L. (Howard O. Yoshida, personal communication). In both specimens the first elongate haemal spine was shaped like that seen in adult *T. alalunga*. The width of the flat section of the spine was 2 to 3 times that of the haemal spines following it. The exact size at which this character develops has not yet been determined, but it seems fairly certain that it is present in juveniles much smaller than 6.0 cm.

The author wishes to acknowledge the critical reviews of this manuscript by Dr. Bruce B. Collette, Dr. Robert H. Gibbs, Jr., and Dr. Ernest A. Lachner. — WALTER M. MATSUMOTO, *U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Honolulu, Hawaii.*



king Him Up, the sea lion sometimes bites and lashes the seized salmon to bits. All photos accompanying article are by the author.

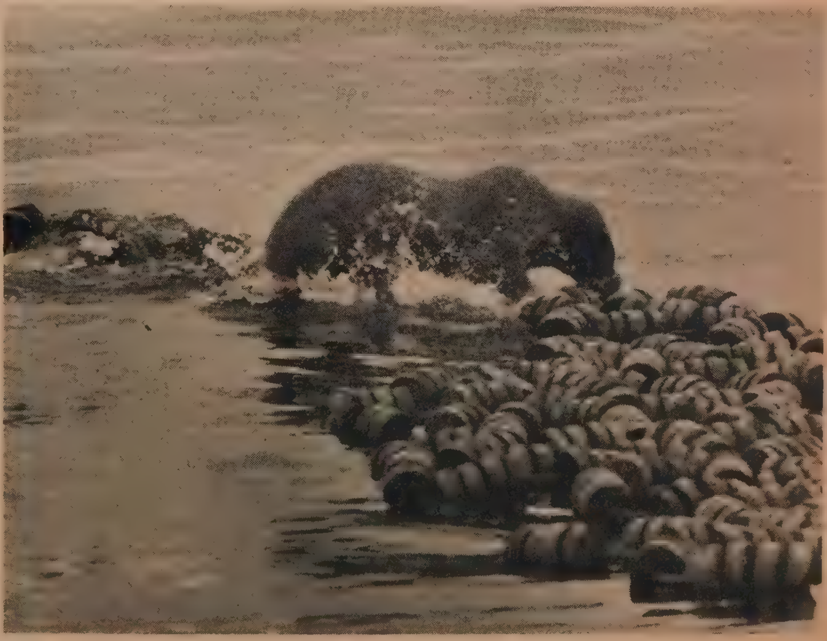
Sea Lions Create Havoc

By THEODORE R. MERRELL Jr.
U. S. Bureau of
ommercial Fisheries Laboratory
Auke Bay, Alaska

Sea lions (*Eumetopias jubata*) rise the ire of commercial fishermen i Alaska wherever fishing fleets and s lions are found. Opinions are often treme, ranging from the view that a lions are a major predator of mon and therefore should be annilated to the opposite view that ey should be preserved and protected because they have little or no fect on commerical fishes, and are interesting segment of Alaska's ldlife. Unfortunately, there is little ientific documentation of just how rious predation on commercial shes by sea lions is.

Alaskan biologists Ted Merrell and red Thorsteinson of the Auke Bay iological Laboratory of the U. S. ureau of Commercial Fisheries had n unusual opportunity during the immer of 1961 to observe and record observations of sea lion predation during a salmon tagging project n the south side of the Alaska Peninsula. The tagging boat was the *California Rose*, an over-limit seiner skippered by A. K. Anderson. Each year n late June a fleet of seiners, and ore recently gill netters, fish south f Unimak Island, intercepting a fast-moving run of Red and Chum salmon migrating north through Unimak Pass into the Bering Sea. In 1961 the open fishing season in this area was from Monday through Friday and several dozen seiners, including the *California Rose*, fished the waters south of Unimak Island.

Details of events for each purse seine set were carefully recorded as part of the tagging record so that later recoveries could be analyzed. A study of sea lion predation was not part of the original experiment, but when serious interference by sea lions developed, observations, documented by photographs, were recorded. The evidence speaks for itself in direct



Over the top method of leaving the net is unusual. Commonly the sea lions tear their way out, wrecking the net. This Merrell photo suggests why the early Russian explorers called the animals "sea bears".

The only medicine for sea lions. Crewman in the tail skiff watches for sea lions to appear in the circle of the seine as the **California Rose** tows on her net and moves in to pick up the skiff.

quotations from the tagging record, which show that during the days open for fishing the harassment of the research vessel was only moderate; but that with the weekly closed period the sea lions concentrated on the *California Rose* to an extent which prevented effective research fishing.

Sea lions were such a problem at times that seining became impracticable. During week days, when many boats were present, sea lions in the vicinity were dispersed among the fleet, but on the weekends of June 17-18 and 24-25, when only the research seiner was fishing, the animals apparently converged on the single boat. Their harassment was most severe the weekend of June 24-25 when 6 hours and 15 minutes of fishing was lost while damaged nets were being repaired. An unknown number of salmon escaped through holes torn in the net.

Several sea lions were wounded or killed in the seine by rifle fire, but their unscathed companions were neither frightened no deterred from pursuit of salmon by the presence of wounded animals. The only effective remedy for relief from harassment by sea lions was to kill each one.

If fishermen would record details of their own experiences with sea lions it would help in evaluating sea lions as predators on salmon or nuisances to fishing fleets. Judging from the experience of the *California Rose*, when a fleet of boats is congregated in an area, sea lions are not much of a problem for any individual boat because their attacks are dispersed throughout the fleet. When only a lone boat is present, however, (as was the cast of the *California Rose* during the closed commercial season) sea lions in the area are attracted to the only available easy source of salmon, resulting in so much damage to the seine that successful fishing becomes impossible.

The problem of sea lion harassment of fishing fleets has been previously recognized by the Bureau of Commercial Fisheries. The Bureau has completed preliminary studies on how to utilize sea lions for commercial products. As utilization of any living resource is preferable to its destruction without use, such an approach may ultimately be adopted to reduce the numbers of sea lions in problem areas.

PMS Ballard Properties Sold To Dave LeClercq

Pacific Marine Supply properties on the north side of the Lake Washington Ship Canal, just east of the Ballard Bridge, have been sold to Dave LeClercq, owner of Seattle's Commercial Marine Construction. The 4½ acre site stretches along 650′ of canal frontage with docking facilities. Seven buildings go with the sale including the 15,000 square foot PMS, Ballard Division and the 4,600 square foot Northwest Instrument buildings. Mr. LeClercq has not made firm plans for the use of the site as we go to press.

Reprinted from PACIFIC FISHERMAN, *November 1963*

MOLLUSKS FROM A BUOY OFF GEORGIA

By ARTHUR S. MERRILL[1]

A recent publication by Galtsoff and Merrill (1962) on the shell morphology, growth, and distribution of *Ostrea equestris* was based principally on a study of the oysters taken from a buoy off the Georgia coast. The present paper discusses all other species of mollusks found on this buoy.

The buoy was examined at the United States Coast Guard Station, Charleston, South Carolina, where it had been brought in for servicing. It had been moored offshore from the St. Mary's River entrance, 30°42'5" N. latitude, 81°19'2" W. longitude, about 6 miles from the nearest land point of Amelia Island, Georgia, at a depth of 30 feet. The buoy had been in the water from 28 February, 1957 to 16 November, 1960.

There was a wealth of molluscan fauna within the stabilizer tube of the buoy (see illustration of buoy stabilizer tube in Merrill, 1959). Especially noteworthy was the predominance of *Ostrea equestris*, but equally impressive were the great numbers of several other species, mostly very small specimens. These occupied an area of about 50 square feet in the tube and all were carefully removed with the assistance of Mr. Richard Spencer of North Charleston, South Carolina.

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[1] Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts.

The mollusks have since been sorted and measured. The size range of some species indicates recent setting. Many individuals are so small that the larval and early postlarval shell characteristics are easily recognizable. Some of the species are so numerous as to permit the arrangement in series of juvenile growth for studies of early shell morphology and variation. In fact, a series of one species, *Lithophaga bisulcata,* has already been described and figured in a study by Turner and Boss (1962).

The mollusks collected from the buoy are listed below with annotations. Greatest overall measurement, either height or length, is used. The pelecypods are deposited at the Museum of Comparative Zoology, Harvard University, where they are readily accessible.

Pelecypoda.

Ostrea equestris Say: 820 specimens measuring 4.0 to 82.0 mm. with two modes at about 15.0 and 48.0 mm.

Chama macerophylla Gmelin: 6 specimens from 3.0 to 10.0 mm.

Noetia ponderosa (Say): 535 specimens from 0.5 to 5.0 mm. with a mode at about 2.5 mm.; 12 specimens over 5.0 mm. to 33.0 mm.

Gastrochaena hians Gmelin: 1 specimen 6.8 mm.

Brachidontes exustus (Linne): 3410 specimens 0.6 to 14.8 mm., mode at 2.5 mm.

Modiolus americanus Leach: 144 specimens 0.9 to 12.8 mm., modes at 2.5 and 5.5 mm.

Musculus lateralis (Say): 38 specimens 2.0 to 8.1 mm., mode at 5.0 mm.

Pododesmus rudis Broderip: 5 specimens 14.5 to 41.5 mm.

Lithophaga bisulcata Orbigny: 11 specimens 1.8 to 18.0 mm.

Gastropoda. The gastropods include 7 larval specimens less than 1 mm. long and one adult pteropod about 5 mm. long. These were sent to Dr. Robert Robertson of the Academy of Natural Sciences of Philadelphia for examination. The larval specimens, too small for positive identification, comprise 4 high spired forms, possibly columbellids, and 3 low-spired ones, possible naticids. The pteropod was identifiable. All the gastropods were catalogued into the A.N.S.P. mollusk collection as follows:

Cavolina longirostris (Lesueur) Cat. No. 255011.
?Polinices (Neverita) duplicata (Say) Cat. No. 255012.
?Mitrella lunata (Say) Cat. No. 255013.

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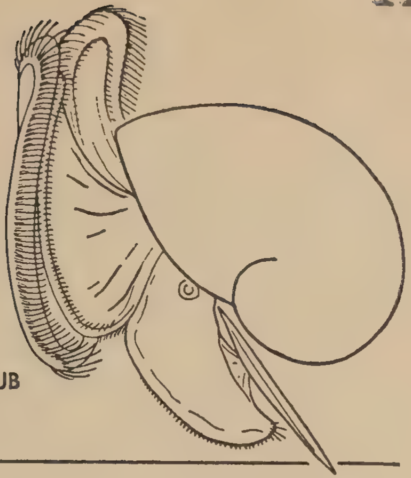
THE VELIGER



A Quarterly published by
NORTHERN CALIFORNIA MALACOZOOLOGICAL CLUB
Berkeley, California

VOLUME 6 OCTOBER 1, 1963 NUMBER 2

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ORDER, Suborder, **DIVISION, Subdivision,** SECTION,
SUPERFAMILY, FAMILY, Subfamily, *Genus*, (*Subgenus*).
New Taxa

Nest Building in the Bivalve Genera *Musculus* and *Lima*

BY

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AND

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Cambridge 38, Massachusetts

(Plates 9 to 11)

The adaptations of bivalve mollusks are numerous. Many species burrow into soft muds and sands,fewer into harder substances only. Others can crawl, leap, and swim, and some live as commensals or parasites. There are sedentary species which attach themselves, temporarily or permanently, to objects by means of byssal threads which they secrete. Among the latter a number of species have developed the process of byssus spinning to the point where they enclose themselves in capsules, or "nests."

Bivalves have two principal methods for constructing nests. One method involves the agglutination of foreign particles with mucus produced by the animal. According to Haas (1942, 1943) these are the main ingredients used in building the nests of *Diplodonta orbella* (Gould, 1851) and *Cooperella subdiaphana* (Carpenter, 1864). The second method, which utilizes byssal threads as the principal constituent, is far more common among nest builders and has been studied most extensively in the case of *Lima* and *Musculus.*

The process of nest building has been observed for *Lima hians* (Gmelin, 1791) by Robertson (*in* Jeffreys, 1863), Gilchrist (1897), and others, but no one, to our knowledge, has kept *Musculus discors* (Linnaeus, 1767) in aquaria and observed the early stages of nest building.

Recently a large number of specimens of *Musculus discors* was acquired during dredging operations of the U. S. Bureau of Commercial Fisheries research vessel *Delaware* (Cruise 62 - 6). These specimens were found in nests, fouling the upper valve of the sea scallop, *Placopecten magellanicus* (Gmelin, 1791), and usually well camouflaged among other fouling growth. They were taken from the Northeast Peak of Georges Bank, off Massachusetts (Lat. 41° 57.2′ N; Long. 66° 16.7′ W), on June 1, 1962, at a depth of 44 fathoms, and were held aboard ship in tanks with running sea water. In the laboratory, specimens of various sizes were removed from their nests and placed in individual aquaria, supplied with running sea water (Plate 9, Figure 1), to see if they would construct new nests. After several days some did. The early phases of construction were observed closely and documented with a series of photographs.

In this paper the process of nest building of *Musculus discors* is described and illustrated; and for comparison, the process for *Lima* is reviewed. In a final section, the adaptive significance of nest building in the two genera is discussed and compared.

NEST BUILDING IN *MUSCULUS*

During the early stages of nest building *Musculus discors* tends to weave a compact structure entirely of byssal threads which it attaches to the substrate. In waters off Cape Cod, Massachusetts, however, the completed nest later becomes well camouflaged, for stolons of hydroids grow into it, small bivalves and annelids nestle among the outer threads, and colonies of bryozoans often overgrow it completely. MacGinitie (1959) described similarly the completed nest of the Pacific variety of this species. Forbes & Hanley (1853) remarked that those in English waters are found "enveloped in nests formed of fragments of *Flustra foliacea* [a colonial bryozoan] and masses of sand agglutinated together and combined by byssal threads." Stimpson (1853) observed that the nests of specimens from the vicinity of New Brunswick are formed of various marine substances. Thus, it would seem that, in a given area, the composition of the completed nest depends in part on the composition of the substrate and on the organisms closely associated with the nest builder.

Musculus discors has no permanent openings in the byssal capsule for water currents to pass through. Rather, the byssal threads radiate from their point of attachment to the animal, and surround the shell in all directions, completely concealing the resting animal. Only when the shell valves are open are the byssal threads separated and the siphons exposed for feeding and respiration.

The foot (Plate 9, Figure 2), in conjunction with special glands, is used in the formation of byssal threads. This highly specialized organ is capable of great extension. When contracted it is short and tongue-shaped, but when fully extended it becomes slender and strap-shaped. The means by which the Mytilidae form and attach threads of conchiolin have been carefully described by White (1937). In essence, the foot has a groove on the posterior side which, at the base, is continuous with the byssal aperture. Secretions issue not only from glands of the byssogenous cavity but also from those lining the groove of the foot. The groove, which terminates in a depression or sucker at the distal end of the foot, is closed during the process of secretion. The sucker is rounded in *Mytilus edulis* (Linnaeus, 1758), but somewhat triangulate in *Musculus discors.* Other glands emit a cement-like secretion into the sucker which forms the adhesive disc at the point of attachment of the thread. To fix a thread the foot extends to the object of attachment, cements the adhesive disc in place, then opens its groove, allowing sea water to enter and harden the white, transparent thread. To see a newly produced thread is not easy because of its transparency, but a bright light shined over an area where the foot has been observed at work will pick up a thread by its reflection. In time, chemical reaction causes the thread to darken; the color becomes light yellow the first day and changes later to progressively darker shades of brown. The threads of *Musculus* are thin and flexible, unlike the thick, stiff ones of *Mytilus.*

The nest is composed of a soft, flexible network of threads which may be likened to a hollow ball of twine. The threads, however, all emanate from a single point, the byssal aperture; and it is only at this point that the animal is attached to its nest, for none of the threads is ever attached to the shell itself. Thus the animal is suspended within the nest, in a manner allowing freedom of movement when opening the valves during feeding and respiration. The animal controls the opening of the nest by the action of the byssal retractor and the two adductor muscles of the shell. When these three muscles are relaxed and the valves open, the byssal aperture becomes situated nearer the shell edges. This extension of the byssal attachment point relieves the tension on the threads and allows them to separate, forming an oval aperture in the posterior-ventral region through which the siphons protrude. When fully extended, the valves open to a considerably wider angle than those of the unprotected species of the mytilids we have observed. Closing of the nest aperture is accomplished by simultaneous contraction of the adductor muscles and of the byssal retractor muscle. As a result, the threads over the ventral margin of the shell are drawn into the mantle cavity; this causes the remaining portion of the nest to be brought into closer contact with the shell, completely hiding it.

Several specimens were observed in the process of nest building and all proceeded in the same fashion. They attached themselves to some object so that they were free of the bottom and could wrap threads completely around themselves in all directions. The specimen described here (Plate 10, Figures 1 and 2) first attached itself high on the side of the aquarium with the right valve towards the glass and the ventral margin uppermost. The first threads attached were directly above the shell and the next were placed in front and behind it. Then the very extensible foot reached out and over the left valve to attach threads on the glass below it. Once these initial "guy ropes" had been put in place, the animal proceeded to strengthen its position by producing several series of threads. Each series was composed of 5 to 12 threads arranged in straight lines. The first series was placed directly above the shell, while others occupied various points around the periphery until 40 or more separate threads had been produced. After this the animal extended its foot around the left valve of the shell and attached threads to those already produced on the opposite side. The first of these threads were placed directly around the central part of the shell,

Explanation of Plate 9

Musculus discors Linnaeus, 1767

Figure 1: Specimen removed from the nest, lying on the right valve and partially opened, showing the incurrent (left) and excurrent siphons (about 4 x) Figure 2: Specimen with foot extended and the tip appressed against the side of the aquarium. Note the byssal groove extending the length of the posterior surface and terminating in the sucker near the tip (about 4 x)

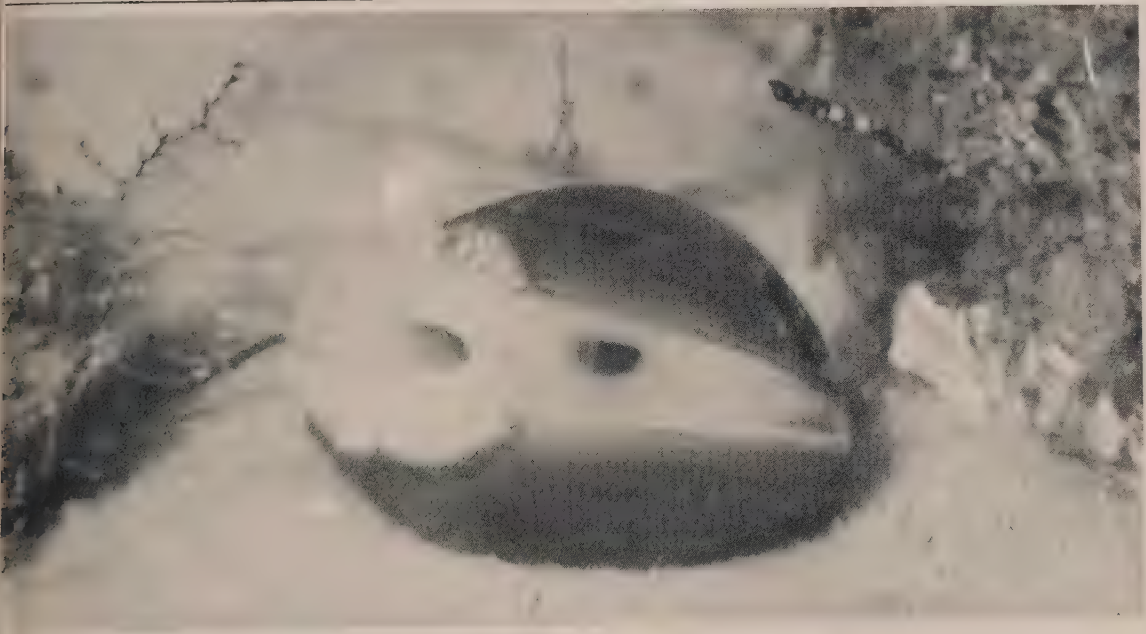

Figure 1

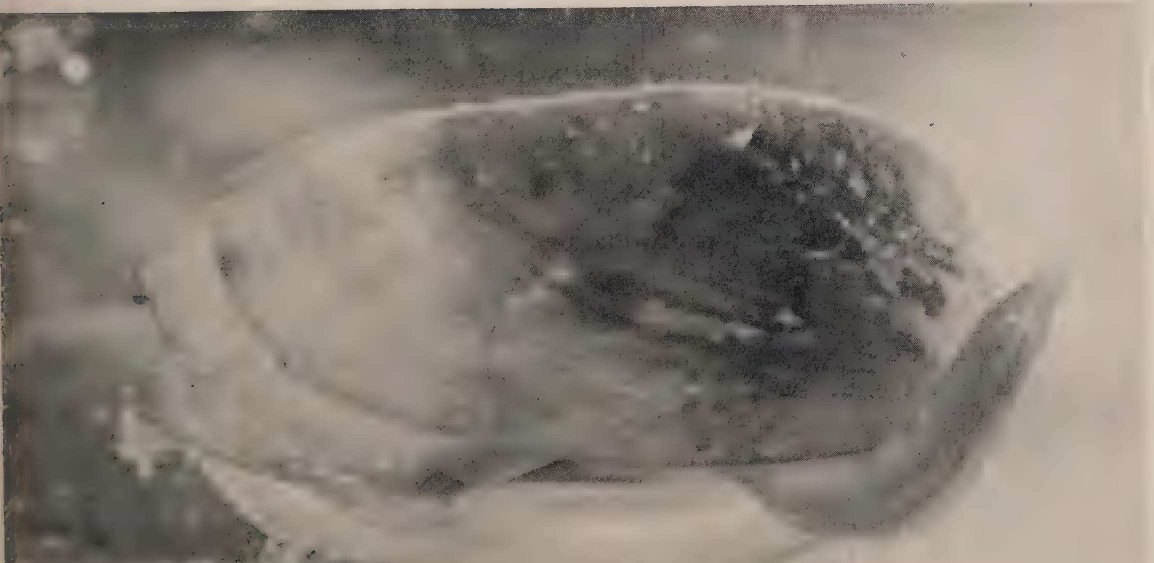

Figure 2

but thereafter they were wrapped diagonally or centrally about the shell. During this stage the remarkable agility and extensibility of the foot were most noticeable. It was also noticed that the foot always extended over the left valve and around itself, but never went in the opposite direction between the right valve and the glass except for purposes of strengthening its position of attachment.

As the nest is being produced bits of mucus and detritus collect between the threads which tend to mat the whole together. Literally thousands of threads are laid down before the nest is completely and securely matted together. After the nest is compact and well established, the animal occasionally passes its foot over and around stationary organisms which have attached to the nest, incorporating these in the outer fringes of the nest (Plate 11, Figures 1 and 2).

One animal, although disturbed intermittently for observational purposes, produced 300 to 400 threads in 8 days. Another, left undisturbed for a period of 2 weeks, had constructed a rather complete but loose nest of perhaps 1000 threads. A third specimen, observed after it had put out 5 or 6 threads, added another 24 strands in the next 2 days, 50 or 60 more during the succeeding 2 days, and over 100 the following 2 days, totaling about 200 threads in a week (Plate 10, Figures 1 and 2).

The animal works sporadically at weaving. The foot will attach several threads industriously and then retire for an indefinite period. Hours may pass before the foot is observed at work again. One animal was seen applying the tip of the foot to the glass side of an aquarium. The spot was marked on the outside of the glass, the slight jar causing the foot to retire. Twenty minutes later, six more adhesive discs, lined in a row, were noticed beside the marked one.

During the early stages of nest building mucus is produced by the mantle glands. As the threads come in contact with the mucus small globules are picked up, collecting like beads on the threads and aiding in the accumulation of adherent detritus, all of which give texture to the partially built nest (Plate 10, Figure 1).

In the field, the size of the smallest specimen of *Musculus discors* which we observed encased completely in its own nest was 8.1 mm. However, specimens up to 18.0 mm were occasionally without nests, but usually specimens over 15.0 mm had at least a rudimentary covering about themselves, and some were already housed in fairly elaborate capsules.

Adult specimens of *Musculus discors* lay egg-strings inside their nests where the embryos develop without any pelagic stage (see THORSON, 1935; MACGINITIE, 1955; and OCKELMANN, 1958 for further details). The young postlarvae remain in the nest near the edge of the adult shell, feeding from the currents produced by the parent. Even larger juveniles are found close to the siphonal area of the parent still clinging in the outer fringes of the nest. It is not unusual to see several small specimens drawn into the mantle cavity of the parent along with the threads to which they are attached when the parent contracts its byssal muscles while closing its valves. According to SUTER (1913), a number of specimens of *Modiolaria* [=*Musculus*] *impacta* (HERMANN, 1782) are usually found in the same nest. Cohabitation of offspring in the nests of their parents is one plausible interpretation of this communal relationship.

THORSON (1935) illustrated the East Greenland form of *Musculus discors* which had drawn together blades of *Fucus* or *Laminaria* by means of byssal threads as part of its encasement. This was reported also for *Modiolaria* [=*Musculus*] *marmorata* (FORBES, 1833) by JEFFREYS (1836); incidentally, both ROBERTSON (1897) and GILCHRIST (1897) mentioned this very phenomenon for *Lima hians*: ". . .nest found with its occupant securely lodged in the folded frond of a sea weed." We have not seen this type of nest construction in *M. discors*, perhaps only because the area in which we found the species did not include appropriate sea weed among its biota. All the specimens we have observed, however, make nests in natural crevices when possible, attaching threads loosely to various places on the substrate before fixing threads about themselves.

NEST BUILDING IN *LIMA*

The nests of several species of *Lima* have been described by a number of authors. GILCHRIST (1897) observed specimens of *Lima hians* (GMELIN, 1791) held in aquaria, and reported the process of nest building for this species. In essence, *L. hians* and presumably other nest building *Lima* construct nests by attaching byssal threads to available fragments of shell, stone, and other debris. It does this by applying the tip of the foot to some object lying nearby, to which it attaches and draws off a fine thread. This process continues, and threads are attached repeatedly to and about nearby fragments. Gradually the nest is bound together by a constant repetition of this process. The internal feltwork is smeared with a slimy secretion from the glandular tentacles which fringe the mantle edge.

Lima hians interlaces byssal threads with nullipores [coralline algae] if they are present (ROBERTSON, 1897), but if building material is lacking, it is capable of making a latticework completely of byssal threads (GILCHRIST, 1897). One specimen which ROBERTSON presented with glass beads fabricated a beautiful nest out of them.

MACGINITIE & MACGINITIE (1949) mentioned that *Lima dehiscens* [of authors, *non* CONRAD (=*hemphilli* HERTLEIN & STRONG, 1946)] builds nests in cavities by attaching byssal threads to the surrounding surface in a scattered fashion, reminiscent of what some spiders do. Forbes & Hanley (1853) stated, "This species [*Lima hians*] can spin for itself a compact nest of byssal threads entangling small stones, shells and fragments of nullipores; in the midst of it lies the *Lima,* resting on a smooth inner coating of fibres."

Lima pellucida C. B. Adams, 1846, has been found on occasion by the senior author living in nests on navigation buoys in the vicinity of Miami, Florida. In these instances, suitable foreign building materials were not present and the nests were constructed in a loose arrangement entirely of byssal threads. Although we observed no special openings for inhalant and exhalant currents, others have. Jeffreys (1863) observed that the nest of *Lima* is funnel shaped; Gilchrist (*in* Jeffreys, 1863) described it as oblong; and MacGinitie & MacGinitie (1949) stated that the nest of *Lima dehiscens* [=*hemphilli*] is open at both ends, a feeding current entering one end and discharging through the other.

Dennis (*in* Jeffreys, 1863), searching for *Lima hians* under rocks, noted as many as seven specimens living in the same nest. Unfortunately no explanation was given as to how this community nest was built. Johnson (1931), while overturning a rock at St. Augustine, Florida, tore a nest apart and revealed a specimen of *Lima inflata* Lamarck, 1819 [=*pellucida*]. Smith (1951) also observed several nests of this species under stones in Biscayne Bay, Florida. Recently, at Lake Worth, Florida, the senior author was fortunate in uncovering several specimens of *L. pellucida* while turning over a rock. Close examination of the rock and the immediate substrate showed no evidence of a torn nest. In this instance the animals were simply hiding in crevices, attached by a byssus. This corroborates remarks by Forbes & Hanley (1853) that *Lima hians* is much more frequently taken free than in nests. When our specimens from Lake Worth were later placed in aquaria containing rocks, they quickly found their way to the deepest and most protected crevices where they soon attached. Gilmour (1963) notes also that *Lima hians* is quick to find protective crevices.

Our specimens of *Lima pellucida* were held in rounded glass containers and their movements observed. The foot of this species is even more agile than that of *Musculus discors,* and just as extensible. However, unlike *Musculus,* the movements of the foot are amazingly coordinated with the swimming movements of the valves and tentacles. When *Lima* is observed to ascend the side of a glass, it appears to flap its valves and swim straight up. Closer examination, however, indicates that the foot first extends upward, the tip attaching to the glass surface. Then the animal actually propels itself forward with a flap of the valve to where the foot is attached. When the forward motion of the shell is about spent, the foot quickly extends and attaches again, repeating the movements as described until it reaches a desired height. The tentacles play an active part in these movements, aiding both in propulsion and in balancing. The coordination of the tentacles, valve muscles, and foot is developed to such a degree that the animal can "walk" up the side of glass almost as fast as it can swim freely. After watching it perform in this manner for a few minutes, one is better able to perceive its ability to find protective crevices so quickly and easily.

COMPARISON OF NEST BUILDING ADAPTATIONS IN *MUSCULUS* AND *LIMA*

The methods of nest building of the species mentioned here are essentially the same in *Musculus* and *Lima* except that the process is more refined in the former. The major difference is that *Lima* incorporates foreign materials in the early phases of construction, if such material is accessible. This allows *Lima* to produce a shelter more

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Explanation of Plate 10

Musculus discors Linnaeus, 1767

Figure 1: Specimen in the early stages of nest building showing byssal threads emanating from between the nearly closed valves near the center of the ventral margins. Note the ball of mucus near the anterior end of the valves (right) and the beads of mucus on the threads. About 200 threads were produced at this time (about 7 x)

Figure 2: Another view of the same specimen showing the byssal threads extending to the side of the aquarium and the adhesive disc at the points of attachment (about 7 x)

Explanation of Plate 11

Musculus discors Linnaeus, 1767

Figure 1: Specimen concealed within a complete and well camouflaged nest (about 3 x)

Figure 2: Same specimen with the valves opened during feeding (about 3 x)

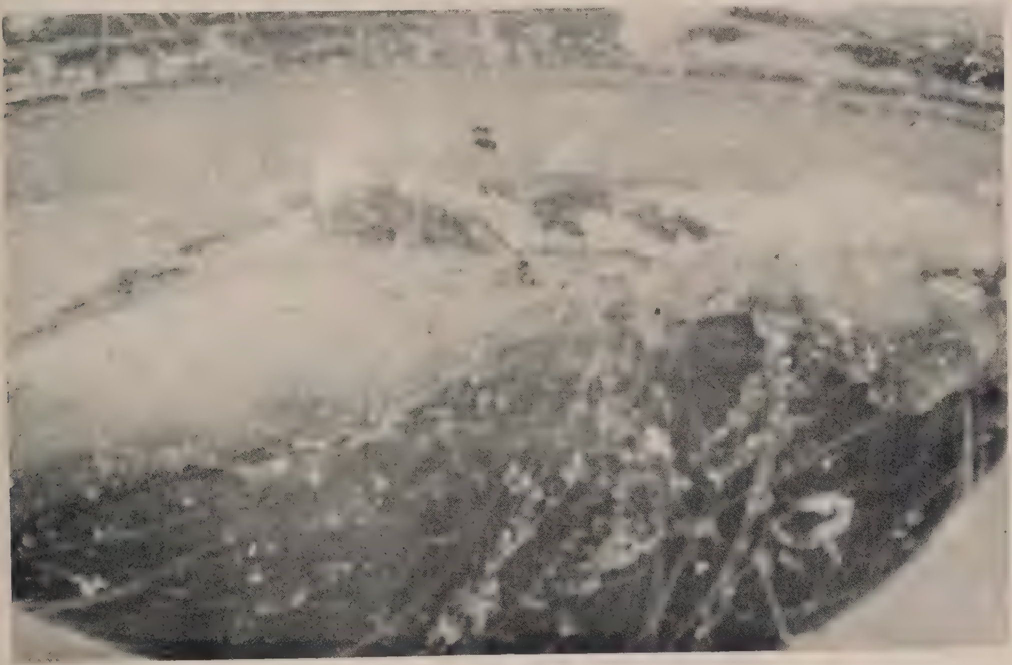

Figure 1

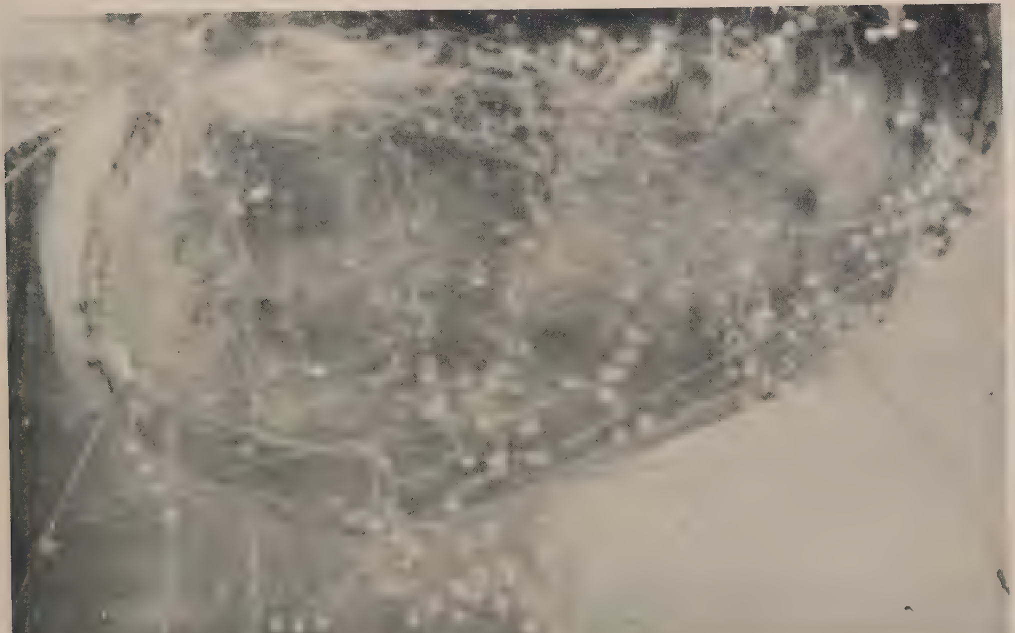

Figure 2

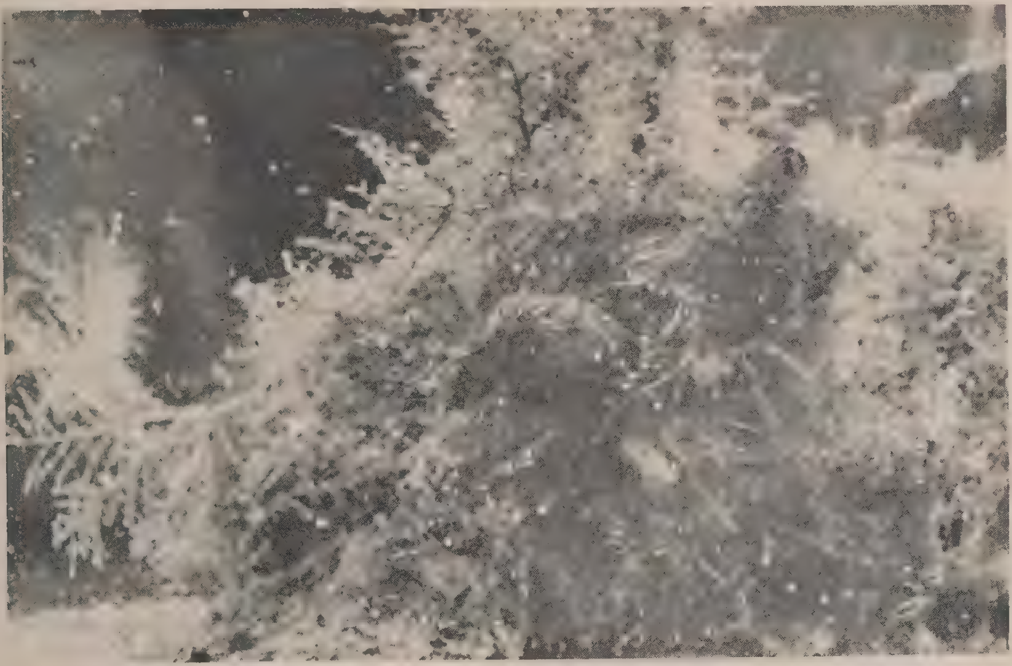

Figure 1

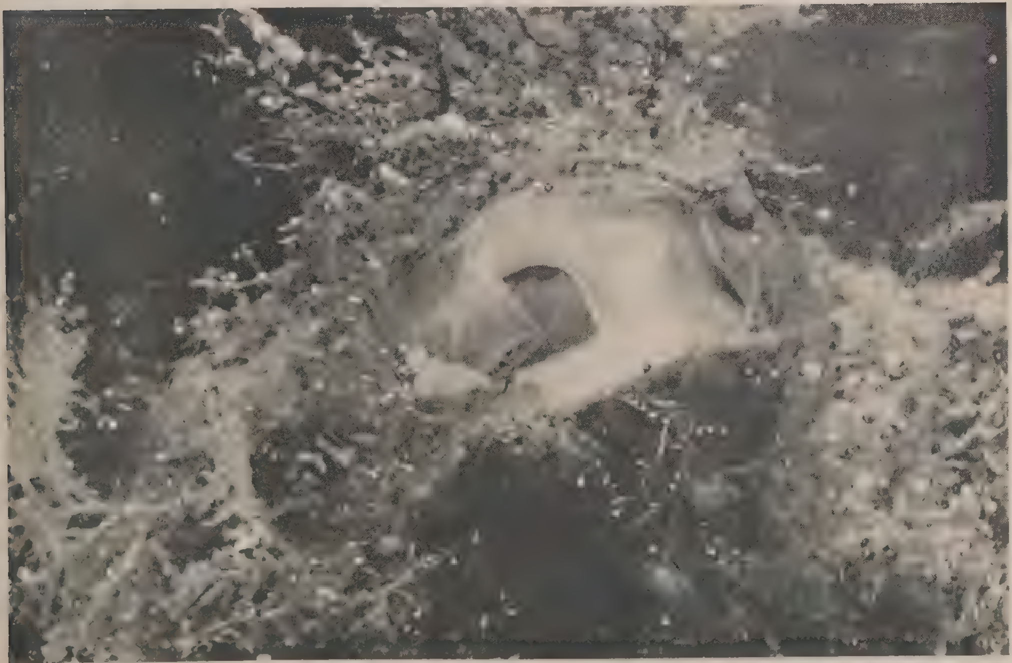

Figure 2

rapidly than *Musculus,* but one that is not as well constructed nor as permanent as that of *Musculus.*

While the byssal capsules are essentially protective coverings, the need for protection is not the same in the two groups. The ability of *Lima* to swim is a means of protection in itself. When feeding, however, *Lima* puts out extremely long and delicate tentacles along the mantle edge which extend well beyond the shell edges. Such a habit would probably make *Lima* extremely vulnerable to predation, as suggested by JOHNSON (1931), if the species were not well protected in crevices or covered with a structure so resembling the surroundings as to escape detection. GILMOUR (1963) postulated that mucus secreted by the tentacles may contain an irritant substance. He found that specimens of *L. hians* were always rejected when attempts were made to feed them to a number of carnivores. However, we saw a carnivore devour a specimen of *Lima*. When specimens of *L. pellucida* were released into an aquarium containing large sea anemones one of them was immediately seized and engulfed by a sea anemone. Later the shell valves only were expelled.

In contrast to *Lima,* which is not able to withdraw completely into its shell at any time, *Musculus* is well protected from predation by a strong shell as is its close relative *Mytilus edulis,* which is not a nest builder. *Musculus* does open its valves wider than *Mytilus,* and in this behavior there may be a reflection of the protection afforded by the nest.

It may be that the nest of *Musculus* has its greatest significance in regard to reproduction and protection of the young. Whereas *Lima* and *Mytilus* extrude their sexual products into the open waters where fertilization and early development take place, *Musculus* deposits its eggs in capsules along the inner lining of the nest where they remain throughout larval and early postlarval development. Protected *Musculus* lay fewer eggs and much larger ones than *Lima* or *Mytilus.* As THORSON (1950) has shown, this fact and the fact that the eggs and young are given protection is typical of marine invertebrates with non-planktonic or only brief planktonic stages in their early development.

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DAVID MILLER, JOHN B. COLTON JR.,
and ROBERT R. MARAK

A STUDY OF THE VERTICAL DISTRIBUTION OF LARVAL HADDOCK

EXTRAIT DU JOURNAL DU CONSEIL INTERNATIONAL
POUR L'EXPLORATION DE LA MER
VOL. XXVIII. No. 1. 1963

A Study of the Vertical Distribution of Larval Haddock

By

David Miller, John B. Colton, Jr., and **Robert R. Marak**

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Introduction

The haddock, *Melanogrammus aeglefinus* L., spends its late juvenile and adult life in the vicinity of the sea bottom. By contrast, however, its early life is spent near the ocean surface. In the north-west Atlantic the eggs are spawned at the bottom between February and May. A few minutes after fertilization, the eggs become buoyant and rise to the surface where subsequent development takes place. By late summer, August to September, the young fish return to the bottom having reached lengths averaging 9–10 cm. Although this pelagic phase is short in terms of the haddock's total life span, it is nevertheless the most poorly understood segment of the total life history and, as Carruthers (1938), Walford (1938), Chase (1955), and others have shown, may be the most critical in determining the year-class strength of adults.

To improve our understanding of this period of development, we need more information on the depth strata which the yong fish inhabit. Diurnal migrations, at least for many species of larval fish, are not as extensive as once surmised, as it has been demonstrated that variations in the day and night catch are due in large part to the ability of many species to avoid slow-moving collecting nets during the daytime (Ahlstrom, 1954; Bridger, 1956 and 1958). However, differential depth distribution of fishes according to species, size, area, time of day and temperature has been observed and recorded by many investigators (Russell, 1928; Sette, 1943; Silliman, 1943; Wiborg, 1948 and 1960; Ahlstrom, 1954 and 1959; Bridger, 1956 and 1958; Colton, Honey and Temple, 1961). This high degree of variability in the vertical distribution of young fishes makes difficult reliable estimates of their abundance over broad geographical areas, due to the physical limitations of time and equipment. Such estimates would demand as a prerequisite a detailed assessment of the vertical distribution of a given species throughout its pelagic period. The results of such studies in more limited areas may establish predictable patterns of distribution so that abundance estimates over large areas might be more easily obtained by sampling only specific depth strata.

The experiments reported herein were designed to delineate the vertical distribution of young haddock larvae, and to determine the efficacy of confining further sampling to a limited depth stratum.

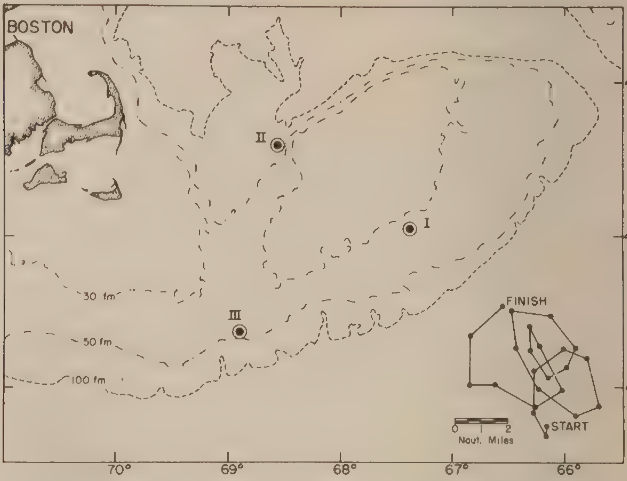

Figure 1. Station locations. (Inset illustrates buoy position at 2-hr intervals during a 46-hr period at Station I.)

Materials and Methods

Collections were made in May 1958 on "Albatross III" Cruise No. 111 at three locations on Georges Bank (Figure 1) where it was known by previous experience that haddock larvae are usually found. Preliminary investigations were made with a series of oblique tows using a 1 m ring-net. Each station was then established at a centre of high concentration of larvae.

An attempt was made to stay with the same water mass by following a free-drifting buoy. The buoy used for the purpose was designed by Robert G. Walden and Joseph McElliot of the Woods Hole Oceanographic Institution. It is 6·1 m long and 0·15 m in diameter and was ballasted to float vertically with 0·6 m of freeboard. An electronic flash lamp fitted to a short mast facilitated following at night.

Each station was occupied for approximately 48 hours. Drift during such a period at Station I is shown in the inset in Figure 1. Such a drift, which is typical of the rotary tidal currents on Georges Bank, occurred at all three stations.

Simultaneous samples were collected at a series of depths by use of the high-speed sampler described by Miller (1961) in conjunction with a U.S. Navy 60-pound kite-otter multiplane depressor as described by Colton (1959). Each sampler consists of a 14·0 cm diameter fibreglass tube with a 10·2 cm sampling aperture, towed from a laterally-placed swivel located just behind the mouth of the tube. A 0·9 m conical collecting net of No. 000 nylon (aperture 0·95 mm) trails from each. Five or six samplers were towed simultaneously on 0·6 cm wire at a speed of 7 knots. Tows of 30 minutes duration were made around the marker buoy at 2-hour intervals at standard sampling depths of 1, 10, 20, 30, 40, 50, and 75 m. All tows were made on a circular course to average out the changing effects of wind and tide on the vessel speed. Bathythermograph lowerings were made at the completion of each tow.

Tests made by the Bureau of Standards, Department of Commerce, Washngton, D.C., showed that the samplers filter 52·4 m³ per standard tow (30 ninutes at 7 knots). Thus, numbers of larvae per m³ were obtained by dividing numbers per tow by 52·4.

For simplicity the word 'larvae' has been used as a general term covering pro-larval, post-larval, and early juvenile stages of development.

Samples were preserved in 5% formaldehyde and all identifications, counts, and measurements were made in the Woods Hole Laboratory. Vertebral counts were used to distinguish between cod and haddock when separation on the basis of external morphological characteristics was uncertain. As less than 1% of the specimens were damaged to the extent that identification was impossible, no adjustment to the data was made for the loss of these fish. There were 393 individual samples of which 14 were discarded because of accident due to faulty setting of the gear. Values representing the average catch per sample at the appropriate depth zone were substituted for these 14 samples in the average larval depth calculations. It was not necessary to use these substituted values in catch-per-tow calculations.

Average larval depths were calculated for each tow by multiplying the number of fish in each sample by the depth at which the sample was taken, summing the weighted samples, then dividing by the total number of larvae taken in the tow. The general trend of changes in depth distribution from tow to tow is shown more clearly by this method than by a simple tabulation of numbers. In addition, by representing the entire distribution at any given time as a single average depth, comparisons with water temperature data are greatly facilitated.

Data by Stations

Station I, 20.–22. May 1958

Station I was located on the south-central part of Georges Bank (Figure 1). One 30-minute tow was made every 2 hours for 46 consecutive hours. The average water depth was 65 m with a minimum of 63 and a maximum of 77 m. Depths sampled were 1, 10, 20, 30, 40, and 50 m. The average surface temperature was 8·4°C. A well defined discontinuity layer, averaging 5 m from top to bottom, was present throughout the sampling period. The centre of this layer fluctuated between 6 and 20 m below the surface. The temperature range within the discontinuity layer was 1·1°C. Below the thermocline the temperature was isothermal to the bottom at 7·2°C.

A total of 1,650 larval fish were taken representing 12 species of which haddock made up 80%, or, 1,316. The catches of the haddock larvae by tow, time, and depth are given in Table 1. The average catch per sample was 9·6 or 0·2 haddock per m³. Catch per sample during the daylight hours (0600–1600 EST) was 9·9 and at night 9·0, a daytime increase in catch in the ratio of 1·1 to 1·0. The average larval depth was 25 m; 28 m during daylight hours and 22 m during the night. Haddock larvae ranged in length from 4 to 19 mm (Figure 2) with a mean size for all depths of 7·4 mm.

The size range, mean length, and length frequency during the day and night were similar. The mean length for all depths during the day was 7·5 mm and at night, 7·3 mm. The mean length and percentage length frequency at each depth sampled for the 46-hour period is presented in Figure 2.

Table 1

Number of haddock larvae taken in each sample at Station I, listed according to water depth and time, 20.–22. May 1958

Tow no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Time (EST)	1800	2000	2200	2400	0200	0400	0600	0800	1000	1200	1400	1600	1800
	Day			Night						Day			
Water depth (m)													
1	2*	1	1	3	1	0	1	0	0	1	8	1	13
10	10	16	49	29	16	9	2	13	18	13	17	8	31
20	19	22	10	11	7	7	9	7	13	16	17	12	1
30	2	22	6	4	6	9	7	33	28	14	15	24	30
40	3	0	4	0	5	5	12	18	20	15	15	15	21
50	1	4	1	1	3	5	5	2	5	0	1	9	19
Total	35	65	71	48	38	35	36	73	84	59	73	69	115

Tow no.	14	15	16	17	18	19	20	21	22	23	24		%		Catch
Time (EST)	2000	2200	2400	0200	0400	0600	0800	1000	1200	1400	1600	Total no.	each depth	Total samples	per sample
			Night					Day							
Water depth (m)															
1	21	0	2*	0	2	0	0	1	0	0	0	54	4·3	22	2·4
10	5	5	10	26	15	5	7	11	13	6	2	336	24·3	24	14·0
20	10	13	15	3	8	8	11*	13	16	14	11	262	19·7	23	11·4
30	27	27	12	0	10	7	19	18	11	6	12	349	25·3	24	14·5
40	17	9	3	6	7	10*	10*	10*	10*	4	16	195	16·9	20	9·8
50	16	3	3	6*	6*	9	11	8	0	8	6	120	9·5	22	5·5
Total	96	57	43	35	42	29	37	51	40	38	47				

* Sample was discarded and appropriate catch per sample value substituted.

Station II, 23.–25. May 1958

Station II, located on the north-eastern edge of the Great South Channel (Figure 1) was also occupied for 46 consecutive hours. Here, the water depth averaged 168 m and ranged from 130 to 187. The sampling depths were 1, 10, 20, 30, 50, and 75 m. Surface water temperatures averaged 8·9°C. The discontinuity layer was broader at this station occupying a zone 14 m in depth, and fluctuating between 8 and 37 m below the surface. The temperature range within this layer was about 3·3°C. Below the thermocline to about 140 m the temperature drop was linear with depth from 5·6° to 5·0°C.

A total of 789 larval fish were taken in which 7 species were represented, haddock making up 89·5% or 671 larvae. The average catch per sample was 4·8 haddock or 0·1 per m^3. The catch per sample during daylight hours was 5·0 and at night 4·4, again showing a slight increase in catch during the day in the ratio of 1·1 to 1·0. The average larval depth for all tows was 20 m. Average depth during daylight hours was 17·8 m and at night 22·5 m, a condition opposite to that prevailing at Station I.

Larvae ranged in size from 55 to 21 mm (Figure 2) with a mean of 11·7 mm. The size range, mean length, and length frequency remained similar during day and night tows. The mean length was 11·9 mm during the day and 11·5 mm at night.

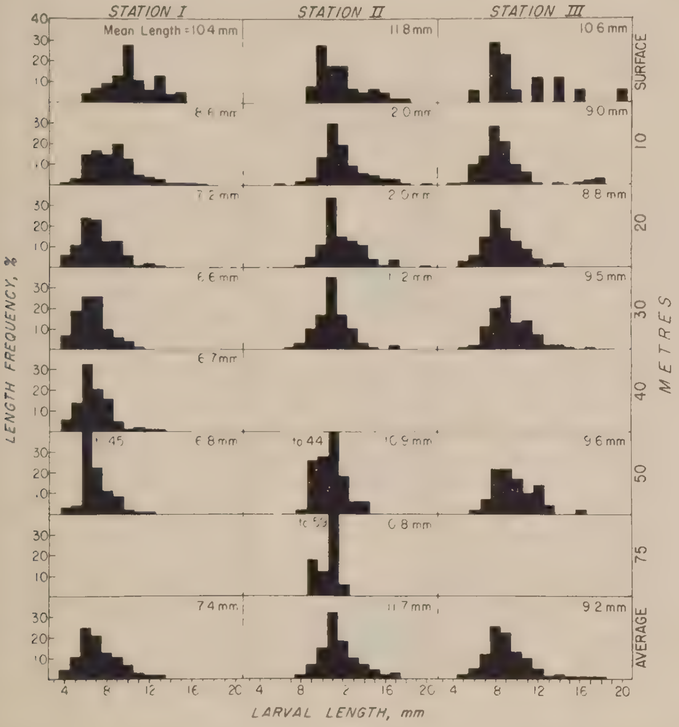

Figure 2. Mean length and percentage length frequency of haddock larvae at each station and depth.

Station III, 26.–27. May 1958

Station III, on the south-eastern edge of the Great South Channel (Figure 1) was occupied for only 40 hours. The water depth averaged 84 m with a minimum of 79 and a maximum of 93 m. Samples were taken at 1, 10, 20, 30, and 50 m. The distribution of temperatures was similar to that at Station II. Surface temperatures averaged 10·1°C. Here the discontinuity layer occupied a zone about 13 m in depth, and oscillated between 9 m and 37 m below the surface. The temperature range within the thermocline was about 2·8°C. Below the thermocline the temperature was isothermal to the bottom at 6·7°C.

A total of 864 larvae were taken in which 9 species were represented, haddock making up about 78% or 677 larvae. The catch per sample was 6·6 or 0·9 haddock larvae per m^3. The catch per sample during daylight hours was 5·6 and at night 7·8, showing an increase in night catches in the ratio of 1·4 to 1·0. The average larval depth for all tows was 24 m, 25 m during the day and 22 m at night.

Larvae ranged in length from 4 to 21 mm (Figure 2), with a mean of 9·2 mm. Again size range, mean length, and length frequency remained similar during the day and night tows. The mean length was 9·3 mm during the day and 8·9 mm at night.

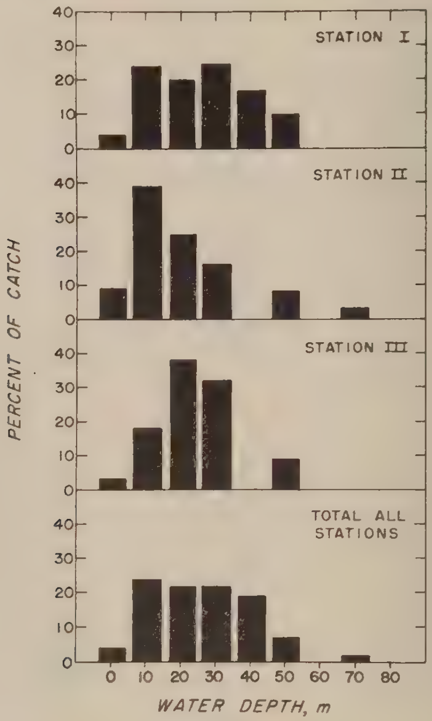

Figure 3. Depth distribution of haddock larvae.

Discussion

Undersampling of pelagic fish larvae during daylight hours is common in many distributional studies. In an investigation of the diurnal movements of the young of some fishes in Danish waters, Johansen (1925) showed night catches exceeding daytime catches for 13 different species. Although no haddock were taken in his study, cod, a close relative, were 2·4 times more abundant in night catches. Russell (1926) in a similar study stated in his summary "... there was, however, a notable increase in numbers of certain species at all depths at night". Russell (1928) again noted the marked disparity between day and night collections. Silliman (1943), Ahlstrom (1948, 1954, and 1959), and Bridger (1956 and 1958), all of whom discussed this problem at some length, made similar observations of various species and, in addition, made quantitative assessments of the escapement. It is significant in the data presented here that the ratio of night versus day catches for haddock is very nearly 1. The night/day ratios are 0·90, 0·86, and 1·40 respectively for Stations I, II, and III, and the ratio for all data combined is 1·05. An analysis of the data on cod, based on a catch of 186 larvae at Station I, shows similar night/day ratios. This similarity in day and night catches indicates that the problem of daytime escapement of haddock larvae has been virtually eliminated by the gh-speed sampling technique used. Based on the assurance provided by these ta that larval numbers and length frequencies within the area sampled remains e same day and night, it can be further concluded that few, if any, larvae grated below the maximum depth sampled at any station.

eneral vertical distribution

The average depth distribution of larvae, disregarding short-term fluctuaons, is shown in Figure 3. Numbers of fish at each depth are expressed in ercentage of the total catch for each station and for all stations combined. ew larvae were found at the surface, less than 5% of the catch being repreented at the 1 m level. Eighty per cent of the total catch occurred between e 10 and 40 m level, while below 40 m catches diminished. If we assume at the distribution of young haddock is continuous between sampling levels, 6 m represents the depth of maximum larval density. These observations are general agreement with data on cod given by Wiborg (1960). In a series f hauls taken in the Austnesfjord to investigate the occurrence of cod fry at ifferent levels, Wiborg found cod most abundant at about 35 m.

Although the numbers of larval haddock declined below 40 m, it is almost ertain that limited numbers venture below the maximum depths sampled at tations I and II (50 m). Whether or not larvae taken at 75 m from Station II ere actually collected at that level, or were contaminants from higher levels, s questionable, as the numbers taken were close to the expected value of the ampling error at that depth (Miller, 1961). In any case these larvae represent nly 2% of the total so that the effect on the interpretation of the remainder f the data is insignificant.

Periodic changes in vertical distribution

At each of the 3 stations continuous change in the depth distribution of haddock larvae was detected. To establish whether or not these changes were recurrent at a given location, a comparison of successive 24-hour periods was made for each station. The results (Figure 4) show that the sequence of change in the mean depth of the larvae during the first day was repeated on the succeeding day for each of the areas sampled. However, depth changes at one locality were not repeated in the same time sequence at either of the other locations. For example, at Station I the larvae rose toward the surface at night and descended to their deepest level shortly before sunrise, while at Station II the larvae were at the deeper levels during the night then rose toward the surface at sunrise. At Station III the sequence of depth change appeared to be intermediate between the other two.

The observation that at each location the daily change in the average larval depth was repeated on the following day demonstrates a basic periodicity which is distinct for each location. This coupled with the lack of continuity between the three stations strongly suggests the influence of a controlling environmental factor, or factors, which are consistent at each station but vary between them. The importance of light in affecting larval distribution would appear negligible inasmuch as the periodicity of this pattern was [illegible] at each station.

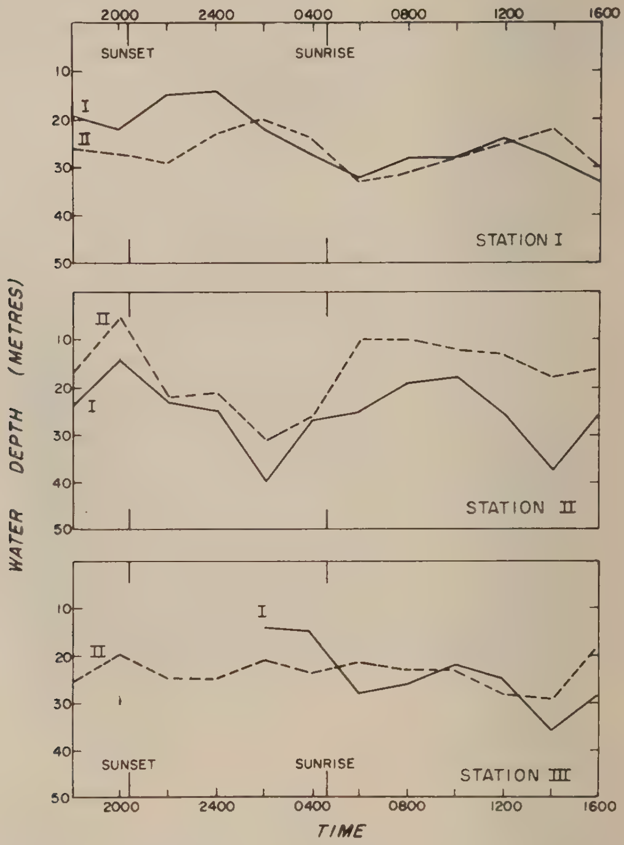

Figure 4. Mean larval depths, comparing first (I) and second (II) 24-hr sampling periods.

Relation of larval distribution to temperature

Inspection of individual bathythermograph records for each tow showed that the thermocline, like the larvae, was continually changing in depth. These changes are apparently related to the rotary tidal currents on Georges Bank. In studies of the plankton of the Florida Current, Moore (1953) showed that siphonophores adjusted their level in response to a depth-changing isotherm. To test for a similar relationship here, a comparison of the depth changes of an arbitrarily selected isotherm within the thermocline layer was made with the average larval depths for the same tows. The initial comparison of these two values at Station I showed no relationship, the average larval depth remaining well below that of the discontinuity layer. However, the bimodal depth distribution at Station I (Figure 3) implies that the total population here is composed of two groups, each exhibiting its own depth preference. To differentiate between these two groups, the relation of size to depth was tested

Table 2

Number of haddock larvae taken in each sample at Station II, listed according to water depth and time, 23.–25. May 1958

Tow no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Time (EST)	1800	2000	2200	2400	0200	0400	0600	0800	1000	1200	1400	1600	1800
	Day			Night						Day			
Water depth (m)													
1	5	4	0	1	0	1	2	3*	0	0	0	0	3
10	8	12*	4	6	4	3	13	0	17	0	0	4	29
20	3	0	4	6	0	15	1	0	4	27	1	10	10
30	3	0	2	9	4	13	1	2	3	0	7	20	0
50	1	3	2	2	10	4	8	1	3	0	3	0	2
75	4	0	0	1	2	1	1	0	0	3	1	0	3
Total	24	19	12	25	20	37	26	6	27	30	12	34	47

Tow no.	14	15	16	17	18	19	20	21	22	23	24	Total no.	% each depth	Total samples	Catch per sample
Time (EST)	2000	2200	2400	0200	0400	0600	0800	1000	1200	1400	1600				
			Night						Day						
Water depth (m)															
1	34	0	1	1	1	0	6	1	0	0	0	60	8·9	23	2·6
10	14	1	2	1	4	45	28	31	26	3	24	267	39·8	23	11·6
20	0	14	14	8	11	0	5	11	10	16	1	171	25·5	24	7·1
30	0	5	6	9	10	0	1	0	1	0	9	105	15·6	24	4·3
50	1	0	0	9	3	0	0	0	0	0	0	51	7·6	24	2·1
75	0	0	0	0	1	0	0	0	0	0	0	17	2·6	24	0·7
Total	49	20	23	27	30	45	40	43	37	19	34				

* Sample was discarded and appropriate catch per sample value substituted.

Table 3

Number of haddock larvae taken in each sample at Station III, listed according to water depth and time, 26.–27. May 1958

Tow no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Time (EST)	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400	0200	0400
	Night					Day						Night		
Water depth (m)														
1	1	0	0	0	0	0	0	0	0	4	0	1	1	0
10	18	19	2	7	1	1	0	3	2	9	1	2	20	4
20	8	8	11	12	8	5	3	9	5	9	24	18	35	21
30	2	4	20	23	3	4	7	6	12	8	10	8	18	10
50	0	0	3	3	0	1	7	5	1	3	3	4	3	3
Total	29	31	36	45	12	11	17	23	20	33	38	33	77	38

Tow no.	15	16	17	18	19	20	21	Total no.	% each depth	Total samples	Catch per sample
Time (EST)	0600	0800	1000	1200	1400	1600	1800				
				Day							
Water depth (m)											
1	3	1	0	1*	0	6	0	17	2·6	19	0·9
10	9	6	6	2	1	5	6	124	17·9	21	6·0
20	23	9	3	22	19	3	13*	255	38·6	20	12·8
30	16	6	13	28	19	3	3	223	32·1	21	10·6
50	2	3	0	8	8	3*	1	58	8·8	20	2·9
Total	53	25	22	60	47	17	10				

* Sample was discarded and appropriate catch per sample value substituted.

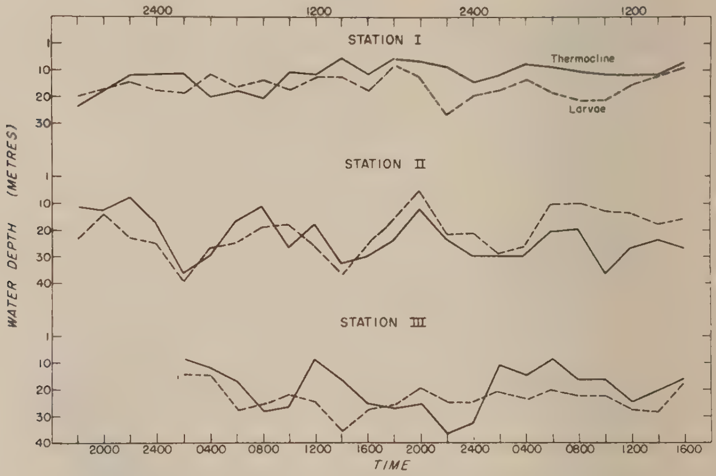

Figure 5. Comparison of mean larval depths with thermocline depths, by tows. Larvae 8 mm and less excluded from data at Station I.

by the method of least squares. The results (Figure 2) show a significant correlation of decreasing larval size with increasing water depth ($r = 0{\cdot}84$ with 5 degrees of freedom). Wiborg (1960) reported a similar depth stratification by size for cod larvae. On the basis of this evidence, the smaller and deeper living fish, larvae 8 mm and less, were removed from the data and the average depth recomputed for larvae from 9–19 mm. This resulted in a marked improvement between larval and thermocline depth fit at this location.

At the remaining two stations where there were proportionally fewer small larvae (Figure 2) no change in the average size distribution with depth could be demonstrated. Consequently, all larvae at these stations were included in the calculations.

A comparison of thermocline depth and larval depth is shown in Figure 5. These comparisons certainly suggest a relation between water temperature and larval abundance. This method of demonstrating the relationship is, however, subject to one major source of error. Although the various sampling zones were equally spaced in terms of depth, these intervals were not so arranged in terms of temperature, as temperature change with depth was not a linear progression, and varied between stations. On this account disproportionately few samples were taken in the discontinuity layer, since it occupied a variable and often small proportion of the entire depth range sampled. In order to give proper weight to each tow in terms of temperature, the water temperature in which each sample was taken was determined by referring to the individual bathythermograph records. From this, the catch per sample for each 0·5°C of temperature was computed. These results are shown in Figure 6. It is apparent from these data that haddock larvae were not equally abundant at all temperatures. There was a marked tendency for the larvae to be more abundant at those temperatures included within the limits of the discontinuity layer. In fact, the data suggest that it is the discontinuity layer itself, rather than any specific isotherm within it, that encompasses the bulk of the young

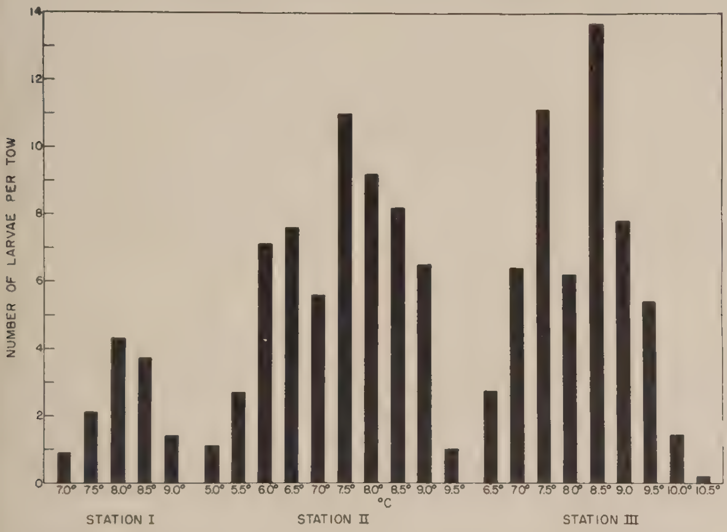

Figure 6. Number of haddock larvae in relation to water temperature.

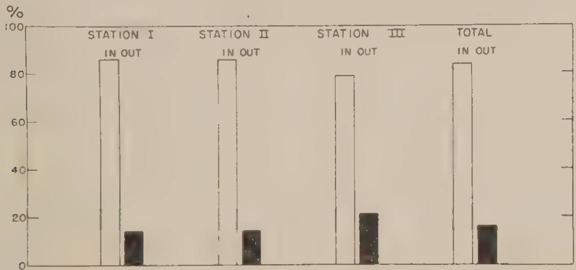

Figure 7. Percentage occurrence of larval haddock within and outside the thermocline.

haddock population. For example, at Station I the catch per sample at the 9° sotherm (located outside the thermocline), was 1·4. On the other hand, at Stations II and III, the catch per sample at the 9° isotherm (in this instance ocated in the thermocline) was 6·5 and 7·8 respectively. To demonstrate this effect more clearly the catch per sample both inside and outside the discontinuity layer was computed. The results expressed in percentages are given in Figure 7. It will be noted that the ratio of the number of larvae within the thermocline, to the numbers without, was very nearly the same for each station, 86%, 86%, and 70% respectively. The combined data for all stations indicate that 84% of the population occurred within this thermally discontinuous water band which occupied about 25% of the entire water column sampled.

In summarizing the vertical distribution of young redfish in the Gulf of Maine, Kelly and Barker (1961) noted that redfish in the 10–25 mm size range were most abundant in the thermocline, and Colton and Temple (1961) found juvenile haddock, 30–130 mm, concentrated in the same zone.

As yet it is not known whether there is a direct causal relationship between temperature and larval distribution, or a more complex relationship where conditions of food, light, pressure, density, and temperature all play a part; each parameter exerting its influence during a specific developmental phase. In any event, the data do demonstrate that haddock larvae in the 8–20 mm size range were concentrated within the limited depth stratum defined by the thermocline. If confirmation of a similar distribution for other areas and times is forthcoming, quantitative measures of abundance will be greatly facilitated by confining sampling to the most productive depth strata.

Summary

1. A study of the vertical distribution of larval haddock at three locations on Georges Bank was made in May 1958, using a high-speed, multi-depth sampling technique. Each of three stations was occupied for 2 consecutive days, one 30-minute tow being taken every 2 hours. Stations were marked by means of a free-drifting buoy in order that sampling would be restricted to a specific water mass.

2. The results indicate that the sampling technique employed was successful in eliminating differences in day and night catches due to larval escapement.

3. An analysis of larval distribution in terms of depth shows that although haddock larvae occurred throughout at least the upper 50 m of the water column, maximum concentrations were centred between 20 and 30 m.

4. Periodic changes in larval depth distribution are demonstrated. The relationship of these changes to periodic fluctuations in the depth of the thermocline is evident. Over 80% of the larvae occurred within the confines of the thermocline.

5. Some evidence from data collected at Station I suggests that very small larvae, 4–8 mm in length had a distinctly different distribution occurring below the thermocline. Evidence to explain this disparity in distribution is lacking.

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IMPRIMÉ AU DANEMARK
ANDELSBOGTRYKKERIET I ODENSE

RACIAL ANALYSIS OF RED SALMON BY MEANS OF SCALES

by
Kenneth H. Mosher, Fishery Research Biologist
Bureau of Commercial Fisheries, Seattle, Washington

ABSTRACT

nethods of determining the continental origin of red 1 the central North Pacific-Bering Sea area—using age nd scale characters—show that North American and l salmon intermingled over a broad area in 1956 and 1957. aracters indicated that western Alaska salmon predomi- om Alaska to the area between longitudes 175°E. and orth of the Aleutians, in 1957 and were also predominant hat area in 1956. The scale characters indicated that lmon predominated westward from the area between es 175°E. and 178°E., north of the Aleutians, in 1957. les were taken there in 1956.

of the Aleutians, scale characters indicated that Asian redominated from Kamchatka to at least longitude 175°E. and western Alaska salmon predominated in the one aken east of 175°E., at longitude 175°W. Samples taken ndicated a predominance of Asian red salmon within the neral area, south of the Aleutians, in which they were it in 1957.

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INTRODUCTION

distribution of red salmon from the North can and Asian continents in the central North -Bering Sea area is of major concern from the standpoint of the Protocol to the International Convention for the High Seas Fisheries of the North Pacific Ocean. In 1956 and 1957, the Japanese high-seas fishery was concentrated in this area from May to mid-July.

This paper presents the development of two methods (by age groups and by features of scale structure) for determining the origin of red salmon, *Oncorhynchus nerka* (Walbaum), a preliminary assessment of the accuracy of the method using scale characters and the results obtained by applying these techniques to the 1956 and 1957 samples taken from May 1 to July 15, in the central North Pacific Ocean and in Bering Sea.

The complex life history of the red salmon points up the possibility that substantial changes might occur in future seasons which would require modification or expansion of the methods presented. These methods, therefore, must be considered as preliminary approaches to the problem of classifying Asian and American fish taken on the high seas. Additional scale data must be studied and further tests must be made in order to determine whether these methods provide a reasonably accurate separation of Asian and North American stocks each year.

This research is the result of team effort by a number of scientists and assistants of the Bureau of Commercial Fisheries as an agency of the International North Pacific Fisheries Commission[1]. Raymond E. Anas and Kenneth L. Liscom were closely associated with the author in the computation of the scale characters. D. D. Worlund and Robert Lander assisted in developing statistical procedures. Fred Cleaver, R. A. Fredin, Rea Duncan, A. C. Hartt, and Drs. R. L. Burgner, T. S. Koo, and George Harry reviewed the manuscript and offered suggestions for its improvement.

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d for publication March 23, 1961. Original, English.
Contribution from the Bureau of Commercial Fisheries, Fish and Wildlife Service, Washington 25, D.C. INPFC ment 395-Rev. 1.
, Int. North Pac. Fish. Comm., 1963.

[1] The Commission, established in 1953 by the International Convention for the High Seas Fisheries of the North Pacific Ocean, coordinates the research of the member nations: Japan, Canada, and the United States. The resulting investigations provide data to the Commission for use in carrying out its duties in connection with fishery conservation problems in the North Pacific Ocean. Publication of this scientific report has been approved by the United States Section of the Commission.

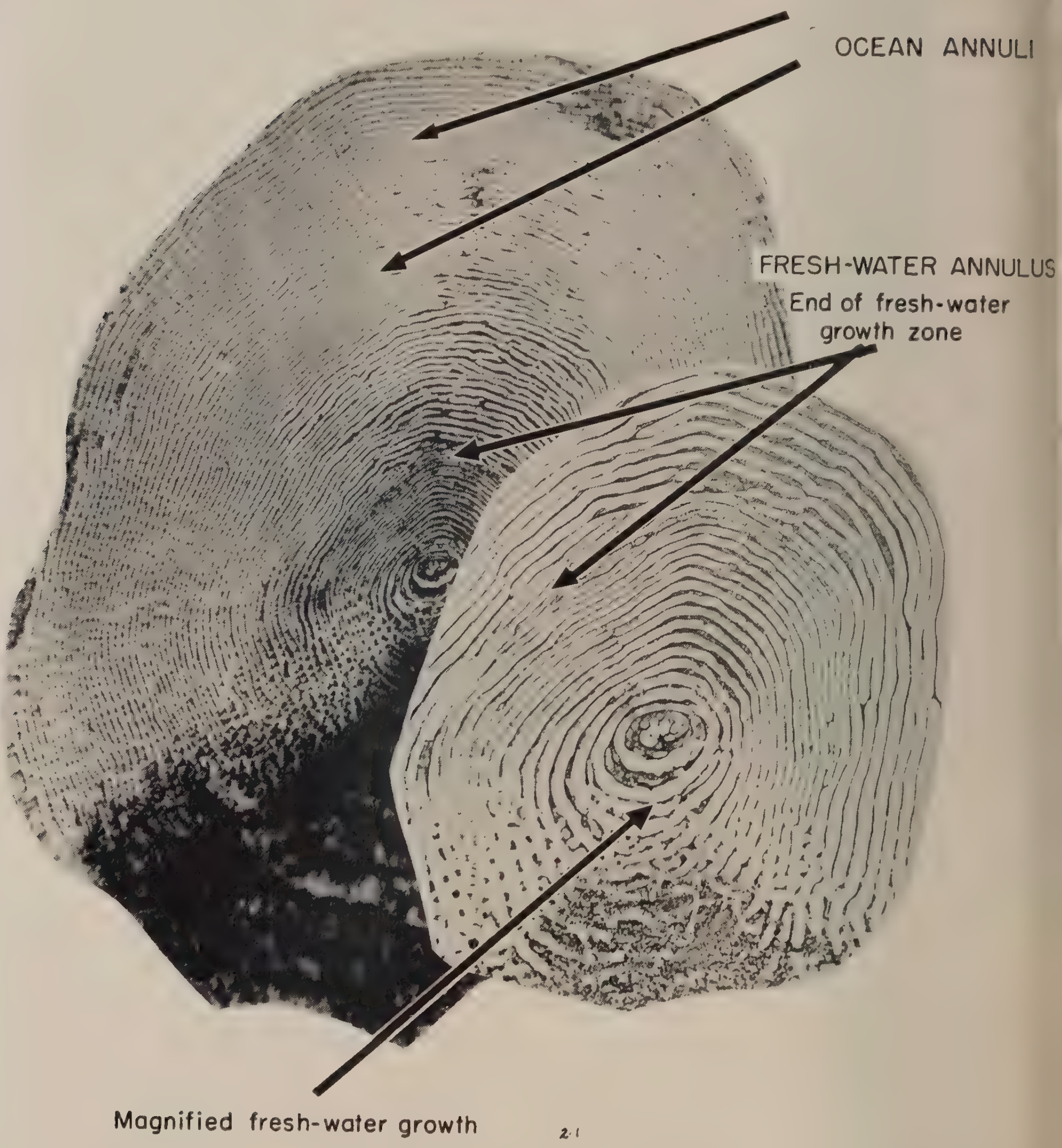


FIGURE 1. Typical scale of red salmon, age 4_2.

HISTORICAL BACKGROUND

Scales of Pacific salmon bear on their surface a sculptured record of the growth experience of the individual fish, showing widely spaced growth marks (circuli) when growth is rapid, and closely spaced ones when growth slows down in the winter or from other causes (Figs. 1 and 2). Interpreting this record and assembling the growth data of individual fish into a composite picture of a race or population has required extensive research over many years, culminating in application to present North Pacific problems.

The practical use of scales for age studies of the Pa
salmon began with Dr. Gilbert's study on the Colu
River in 1910 (Gilbert, 1913). For many yea
was closely associated with age and growth stud

The designation of red salmon ages used in
report follows the formula devised and used by Gi
and Rich (1927). The first digit indicates the
of life of the fish at maturity or capture, counting
the time the eggs were deposited; the second
indicates the year of life from spawning to sea
migration. The age of a salmon may be writte

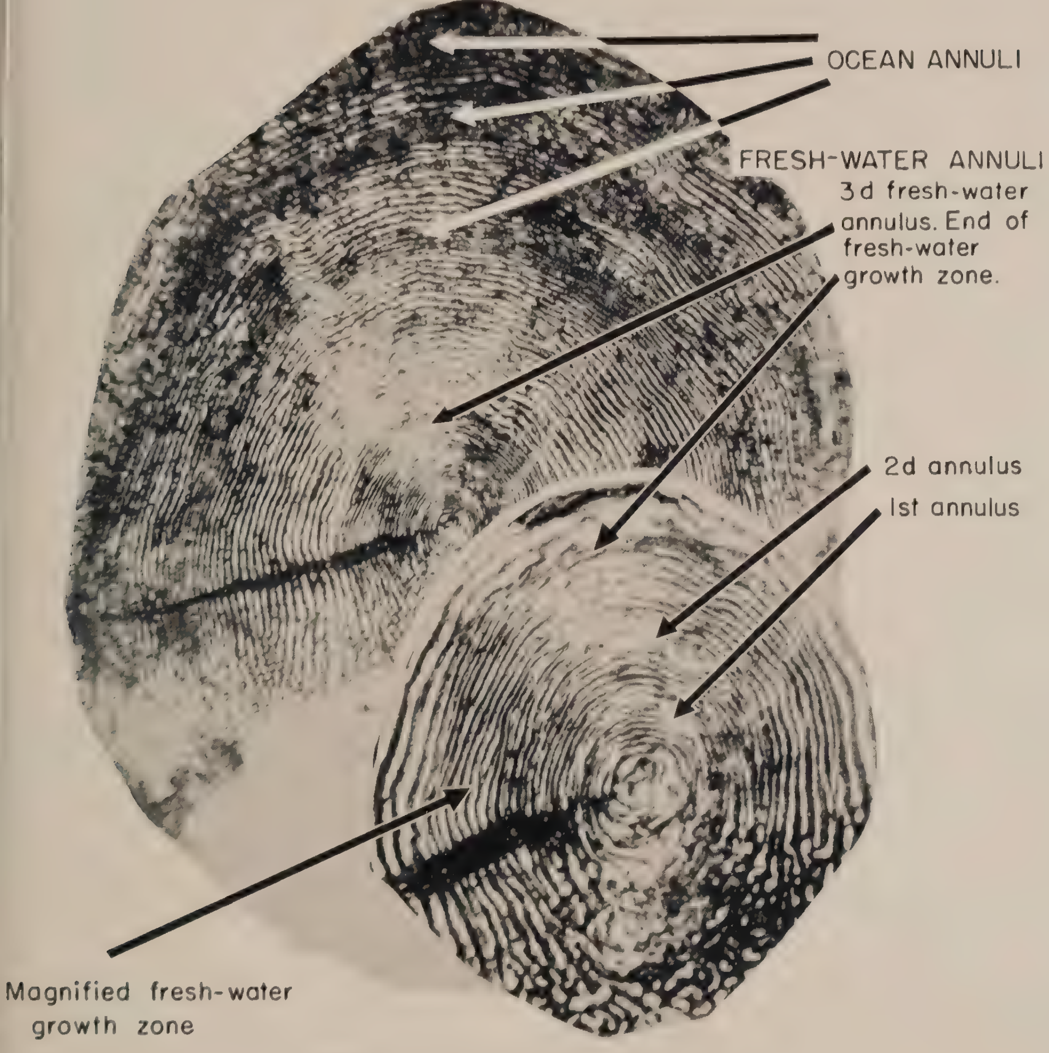

OCEAN ANNULI
FRESH-WATER ANNULI
3d fresh-water annulus. End of fresh-water growth zone.
2d annulus
Ist annulus
Magnified fresh-water growth zone

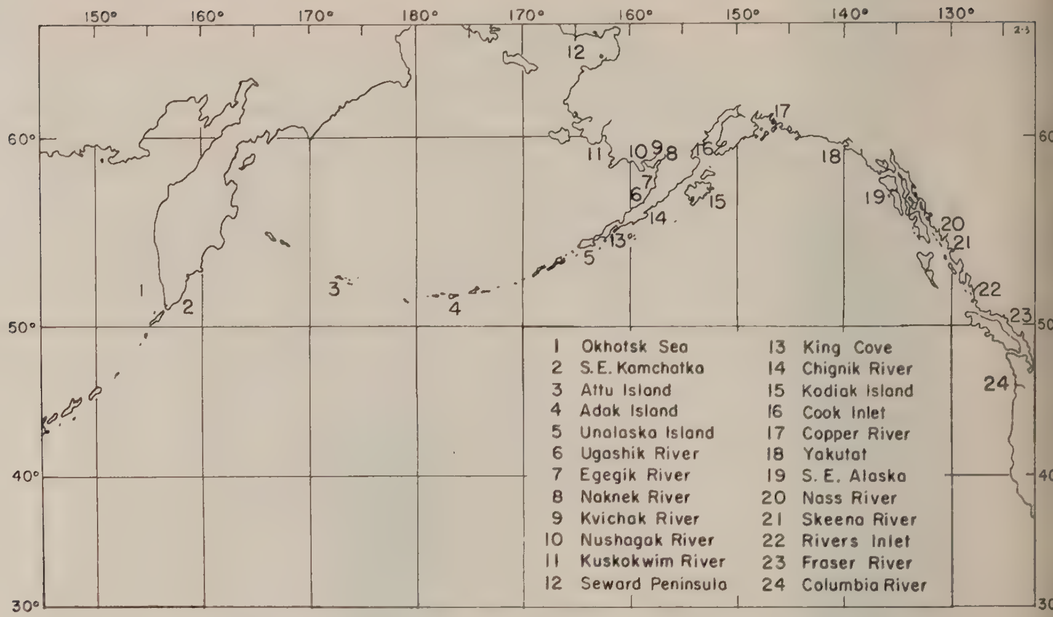
FIGURE 2. Typical scale of red salmon, age 7_4.

l so on. The second digit, alone, indicates the vater age, and is written 2-year fresh-water, fresh-water, and so on.

le he was working for the Fisheries Research of Canada on Fraser River red or sockeye , Dr. Gilbert also proposed a method for ting races by means of circulus counts of the vater growth zone of the scales (Gilbert, 1914

ing the ensuing years Dr. Gilbert's ideas were led and improved by others working with Fraser salmon. The observed abundance and timing s through the fishery and up the river to the ing grounds and the observed scale characters of the young at out-migration linked with the returning adults a few years later have enabled International Pacific Salmon Fisheries Commission scientists to identify certain of the more important races of the Fraser River sockeye salmon some distance from the home stream.

A preliminary survey of the subject of racial determination of salmon for the International North Pacific Fisheries Commission indicated that scale characters had never been used to separate continental stocks of salmon. The research reported here, therefore, represents a part of the first concerted attempt to develop a satisfactory method of using scales to identify the continental origin of salmon. This paper covers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1 Okhotsk Sea
2 S.E. Kamchatka
3 Attu Island
4 Adak Island
5 Unalaska Island
6 Ugashik River
7 Egegik River
8 Naknek River
9 Kvichak River
10 Nushagak River
11 Kuskokwim River
12 Seward Peninsula
13 King Cove
14 Chignik River
15 Kodiak Island
16 Cook Inlet
17 Copper River
18 Yakutat
19 S. E. Alaska
20 Nass River
21 Skeena River
22 Rivers Inlet
23 Fraser River
24 Columbia River

FIGURE 3. Mainland or inshore sampling localities for red salmon, 1956 and 1957.

material and methods reported in a number of progress reports presented at annual meetings of the International North Pacific Fisheries Commission, beginning in 1956.[2] At the 1958 and 1959 meetings, reports on the same subject were also presented by Dr. Tatsuro Kubo (Kubo, 1958; Kubo and Kosaka, 1959).

COLLECTION OF SAMPLES

To provide material for the racial studies, whole fish were collected by several agencies cooperating in a program developed and approved by scientists of the International North Pacific Fisheries Commission. Fish collected in rivers and on the high seas were frozen and transported to the U.S. Bureau of Commercial Fisheries Biological Laboratory at Seattle where they were subjected to complete meristic examination. Scales were taken for analysis at this time. Location of the inshore or mainland sampling areas is given in Figure 3. Tables showing the numbers of whole red salmon caught or sampled for the racial studies by the United States can be found in the annual reports of the International North Pacific Fisheries Commission for 1956 and 1957 (1957, 1958). Tables 1 and 2 show the actual numbers of fish used in this study.

SELECTION AND READING OF SCAL

Some problems are basic to age determination fish species whether it be sardines, herring, tro salmon and they must be examined before any clusions can be drawn. We have studied problems, using methods which have been devel over many years by scientists experienced in fish- analysis.

Simple procedures can be used when the a the fish is the end result, but when circulus co size of scale growth zones and other data for r analysis are determined, the methods must be complex. (Gilbert, 1914 to 1920; Walford Mosher, 1950a, 1950b; Clutter and Whitesel, 1

In any classificatory procedure it is desirab minimize the variation between individuals o same population. One possible source of vari is the differences existing between scales taken different parts of the body of a fish. Kelez (1 and Hokkaido-ku Suisan Kenkyu Jo (*circa* 1 working with adult red salmon, and Koo (1955) Clutter and Whitesel (1956) working with juve report that differences are slight between most adj scales but are often quite large between scales from widely separated areas of the fish body around the fins. The author has observed si differences during the past 10 years in his studi red salmon scales. To minimize errors introduce comparing scales from different areas on the fish

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[2] Some of the preliminary results summarized in Figures 25 and 26, page 94, of the Annual Report of the International North Pacific Fisheries Commission for 1959 have been changed as a result of further analysis.

1. Samples of red salmon collected in inshore s, 1955–57.

	Location[1]	Number in sample 1955	1956	1957
ea	1	82	504	505
iver[2]	1	—	91	30
River[2]	1	—	95	—
n Kamchatka:				
of 54°N. from 157°E.				
4°E.	2	91	144	701
atka River[2]	2	—	101	46
slands:				
sland	3	29	191	110
sland	4	—	203	—
ka Island	5	—	140	—
y:[3, 4]				
k River	6	83	139	135
River	7	85	174	139
k River	8	38	172	497
ak River	9	89	156	156
gak River	10	13	153	56
h:				
kwim River	11	22	—	98
, Teller (Seward Penin-)	12	4	38	52
eninsula:[4]				
Cove	13	31	161	170
ik River	14	37	99	169
sland:[4]				
k River	15	128	217	250
River	15	30	166	178
areas	15	75	—	—
et:				
Creek	16	141	159	—
nwood Creek	16	—	19	—
iver	17	112	219	201
Bay	18	—	65	171
tern Alaska:				
sburg	19	79	161	207
ikan	19	121	167	199
Columbia:				
River	20	24	88	85
a River	21	119	179	181
rs Inlet	22	63	201	79
r River	23	169	186	177
a River	24	33	163	74
TOTAL		1,698	4,551	4,666

Figure 3 for location.

le samples only.

erican standards for 2-year and 3-year fresh-water fish.

erican standards for 4-year fresh-water fish.

TABLE 2. Samples of red salmon collected on the high seas, by vessel and locality, 1956 and 1957.

Vessel and locality	Date	Number of fish in sample[1]
	1956	
Japanese high-seas fishery:		
50°30′ N., 176°07′ E.	May 25	59
50°22′ N., 176°04′ E.	» 28	84
52°08′ N., 170°52′ E.	June 5	91
51°38′ N., 173°38′ E.	» 16	75
51°40′ N., 170°58′ E.	» 15	152
51°56′ N., 172°30′ E.	» 15	99
53°25′ N., 178°24′ E.	» 26	170
49°35′ N., 171°46′ E.	July 6	104
J. R. V. *Takuyo-maru*:		
48°35′ N., 172°16′ E.	June 15	65
MV *Mitkof*:		
50°51′ N., 175°00′ E.	June 15–16	64
53°58′ N., 180°	July 6–11	14
MV *Tordenskjold*:		
56°00′ N., 170°00′ W.	June 20	294
TOTAL		1,271
	1957	
J. R. V. *Etsuzan-maru*:		
48°23′ N., 164°05′ E.	May 18	15
51°15′ N., 169°02′ E.	» 21	39
52°31′ N., 168°27′ E.	» 25	44
51°28′ N., 169°55′ E.	» 27	39
49°02′ N., 167°25′ E.	» 31	66
J. R. V. *Kano-maru*:		
48°02′ N., 167°22′ E.	May 19	33
48°08′ N., 167°40′ E.	» 21	30
49°39′ N., 171°00′ E.	June 1	17
49°55′ N., 175°02′ E.	» 6	14
Japanese high-seas fishery:		
52°33′ N., 166°04′ E.	June 20	85
58°15′ N., 179°10′ E.	» 27	59
51°40′ N., 167°27′ E.	» 28	33
58°10′ N., 177°17′ E.	July 1	39
54°51′ N., 170°24′ E.	» 6	36
57°02′ N., 169°11′ E.	» 12	31
57°26′ N., 167°27′ E.	» 13	34
58°12′ N., 166°48′ E.	» 15	46
MV *Pioneer*:		
56°00′ N., 175°00′ E.	June 10	38
50°00′ N., 175°00′ E.	» 11	58
50°00′ N., 175°00′ E.	» 12	52
53°00′ N., 175°00′ E.	» 14	6
53°00′ N., 175°00′ E.	» 20	52
53°00′ N., 180°	» 22	45
56°00′ N., 175°00′ W.	» 29	7
56°00′ N., 175°00′ W.	» 30	36
53°00′ N., 175°00′ W.	July 3–6	6
51°00′ N., 176°00′ W.	» 8	41
MV *Attu*:		
50°00′ N., 175°00′ W.	May 28–31	20

Continued 36

Vessel and locality	Date	Number of fish in sample[1]
53°00′ N., 175°00′ W.	June 8	49
53°00′ N., 175°00′ W.	„ 9	54
53°00′ N., 175°00′ W.	„ 10	42
56°00′ N., 175°00′ W.	„ 15	184
56°00′ N., 173°00′ W.	„ 17	141
56°00′ N., 170°00′ W.	„ 18	85
56°52′ N., 170°00′ W.	„ 19	65
56°00′ N., 170°00′ W.	„ 20	9
56°00′ N., 168°00′ W.	„ 21	58
56°00′ N., 166°00′ W.	„ 22	83
56°00′ N., 166°00′ W.	„ 23	19
55°00′ N., 166°00′ W.	„ 24	13
56°00′ N., 165°00′ W.	July 10	16
TOTAL		1,839

[1] Includes all fish aged; some were found to be unsuitable for further racial analysis.

endeavor to obtain the identically placed scale from each fish. If this scale is missing or deformed we take the nearest one to it. The position of the scale is noted and recorded. This procedure was approved by the Scale Analysis Work Party which met at Nanaimo, British Columbia, in October, 1957, and is reported in the Proceedings of the Annual Meeting of the International North Pacific Fisheries Commission, 1957, pages 70 and 73. Only scales from the " A " position, as shown on page 73 of the report and in Figure 4 in this paper, are used in our analysis.

The following conditions force the elimination of the scale and consequently the fish from analysis: (1) all scales missing from area A; (2) the scale selected for analysis is regenerated so that the record of the early life of the fish is missing; (3) the margins of the scale are so badly absorbed or eroded away that one or more annuli are missing; (4) the scale is he scarred; or (5) the scale is represented by a defe impression.

To prepare the scales for examination and mea ment they were mounted sculptured side u gummed kraft paper tape 2½ inches wide. Pl impressions of the sculptured side were made press of the type described by Koo (1955) and Cl and Whitesel (1956). The impressions were studied by projection on a device similar to described by Mosher (1950).

A permanent record of the scale was made specially printed card (Fig. 5) graduated in mill ters along one edge. The card was placed u the projection, which was a 42.5 times magnific of the scale, and the zero point was adjusted to center of the scale nucleus. A line perpendicul the base of the sculptured portion of the scale passing through the scale nucleus was determi All counts and measurements were made with 20° arc centered on the perpendicular line. graduated edge of the card was positioned along maximum radius of the fresh-water zone of the s If numerous broken or otherwise indeterminable ci occurred along this radius, the edge of the card positioned along the maximum radius of the w scale. If numerous uncountable circuli occu along this radius also, a radius was chosen w most nearly coincided with the perpendicular If no satisfactory radius could be found, the was discarded for the purpose of this study. number so discarded was less than one percen the total.

For each scale used in this study, the positio the outermost circulus of each annulus was reco

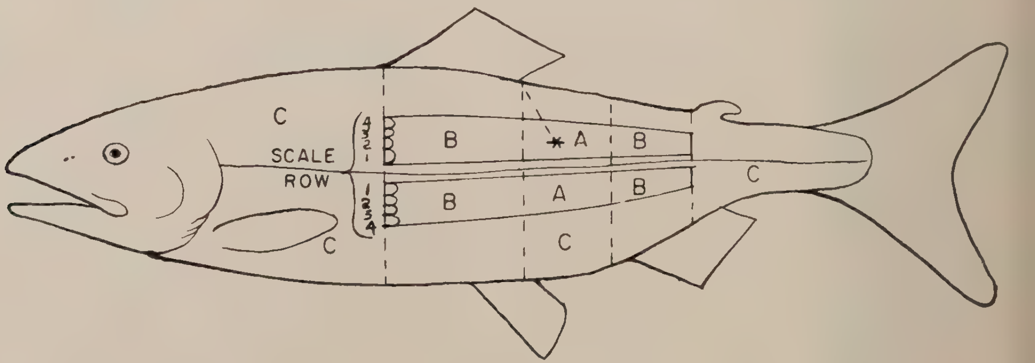
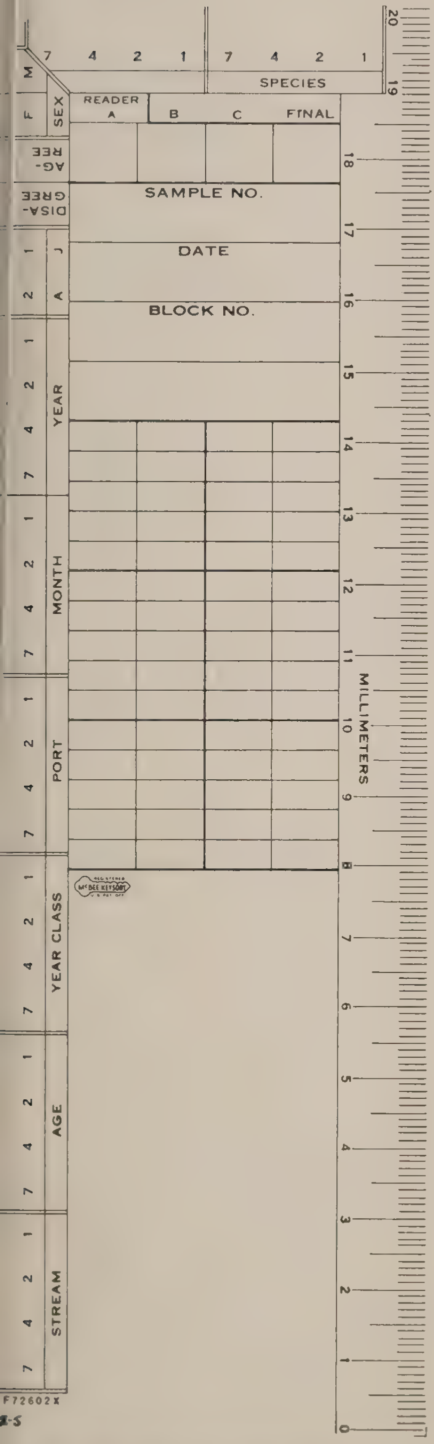


FIGURE 4. Scale sampling code used by agencies of the International North Pacific Fisheries Commission. (*Note:* The asterisk denotes the preferred scale, which can be found by following the diagonal scale line from the posterior edge of the dorsal fin to the second scale row above the lateral line.)



5. Scale card (actual size) used for recording and com-
scale characters.

on the graduated edge of the card, and the number of circuli either complete or incomplete that crossed the edge were counted and recorded on the appropriate position on the card. Thus, the printed card provides a record of the fresh-water, ocean and total age of the fish and the number of circuli and the size of each growth zone. Additional characters could be obtained by subdividing the scale or growth zones.

All scales used in this study were read by two or more scientists experienced in salmon scale studies. As a routine the scales were divided into two or three approximately equal groups depending on the number of workers assigned to the project. Each reader aged and noted the scale characters on the scale card for his share of the scales. Another worker made a second reading of the scale and compared it with the original determination, but he did not make a card. Differences were sometimes observed between scale readers in age determinations—fresh-water, ocean or total—circuli counts and scale-zone measurements. Whenever any difference in age determination or a difference of two or more circuli per growth zone or a difference of three or more millimeters per scale zone occurred, the scale was subjected to joint study and a single age, count or measurement was agreed on.

Studies are being conducted to measure the extent of classificatory errors caused by errors in age determinations, by differences in circuli counts of one per growth zone, or differences in measurements of one or two millimeters per growth zone.

The complete list of ages at maturity which have been found in red salmon samples during the many years of study includes 3_1, 3_2, 3_3; 4_1, 4_2, 4_3, 4_4; 5_2, 5_3, 5_4; 6_2, 6_3, 6_4, 6_5; 7_3, 7_4, 7_5; 8_4 and 8_5 (Barnaby, 1944).

The bulk of the fish (95–99 percent) occur in the 4_2, 5_2, 5_3, 6_3, 6_4 and 7_4 age groups, but a few of the 3_2, 4_3, 5_4, 6_2, 7_3 and 8_4 have been found each season of our present study. The ages are not found randomly distributed throughout the geographical distribution of red salmon; certain age groups tend to occur more frequently in certain areas. For instance, Fraser River fish are predominantly age 4_2 and the fish from some southeastern Alaska areas predominantly age 5_2 at maturity.

DETERMINING CONTINENTAL ORIGIN OF STOCKS

Origin Indicated by Age Groups

The goal of this study was to develop as simple a method as possible that would indicate the continental origin of red salmon taken on the high seas. Since

TABLE 3. Percentage age composition of red salmon collected in inshore areas, 1956.

Locality	Percent in age group																	
	3_1	3_2	4_1	4_2	4_3	5_1	5_2	5_3	5_4	6_2	6_3	6_4	6_5	7_3	7_4	7_5	8_4	8_5
Ozernaya[1]	—	—	—	—	—	—	—	31.5	—	—	15.8	17.9	—	5.3	29.5	—	—	—
Bolshaya[1]	—	—	—	1.1	—	—	34.1	8.8	—	29.7	13.2	4.4	—	2.1	6.6	—	—	—
Kamchatka River[1]	—	—	1.0	—	—	—	49.5	5.9	—	8.9	28.7	—	—	5.0	—	—	1.0	—
Okhotsk Sea	—	—	—	6.4	—	—	24.0	14.5	.3	.5	41.1	5.9	—	1.5	4.8	.5	.5	—
Eastern Kamchatka	—	—	—	5.1	—	—	4.0	33.3	—	.5	16.1	24.1	—	.5	14.8	—	.8	.8
Bristol Bay	—	—	—	42.2	—	—	14.6	29.3	—	.1	12.1	1.1	—	.1	.5	—	—	—
Far North	—	—	—	—	—	—	5.3	7.9	—	—	76.3	—	—	2.6	7.9	—	—	—
Kodiak Island	—	—	—	18.3	.3	—	.5	18.8	—	—	18.3	27.9	—	.3	14.1	—	—	1.5
King Cove	—	—	.6	13.7	—	1.2	39.2	9.3	—	—	33.6	1.2	—	.6	.6	—	—	—
Chignik River	—	—	—	1.3	—	—	10.1	3.8	—	—	82.2	—	—	—	1.3	—	1.3	—
Cook Inlet	—	—	—	67.4	—	—	29.8	2.2	—	—	.6	—	—	—	—	—	—	—
Copper River	—	—	2.0	33.8	—	.5	59.2	1.0	—	—	3.5	—	—	—	—	—	—	—
Yakutat	—	—	6.1	24.6	—	—	43.1	7.7	—	—	18.5	—	—	—	—	—	—	—
Southeastern Alaska	—	—	2.1	10.4	—	—	68.6	7.3	—	—	11.0	.3	—	—	.3	—	—	—
Nass River	—	—	1.1	29.5	—	—	20.5	40.9	—	—	8.0	—	—	—	—	—	—	—
Skeena River	—	.6	.6	83.2	.6	—	13.3	.6	—	—	1.1	—	—	—	—	—	—	—
Rivers Inlet	—	.5	.5	17.4	—	—	79.1	1.5	—	—	1.0	—	—	—	—	—	—	—
Fraser River	.5	—	—	76.9	—	—	21.0	1.6	—	—	—	—	—	—	—	—	—	—
Columbia River	—	13.5	—	70.6	—	—	6.1	9.8	—	—	—	—	—	—	—	—	—	—
TOTAL																		

[1] Scale samples only.

TABLE 4. Percentage age composition of red salmon collected on the high seas, by vessel and locality, 1956.

Vessel and locality	Date	Number of fish[1]	Percent in age group								
			4_2	4_3	5_2	5_3	6_2	6_3	6_4	7_3	7_4	Other
Japanese high-seas fishery:												
50°30′ N., 176°07′ E. 50°22′ N., 176°04′ E.	May 25 » 28	135	24.4	—	14.1	39.3	2.2	18.5	1.5	—	—	—
52°08′ N., 170°52′ E. 51°40′ N., 170°58′ E.	June 5 » 15	243	9.9	—	17.3	28.8	1.2	28.4	3.3	2.1	8.6	.4[3]
51°38′ N., 173°38′ E. 51°56′ N., 172°30′ E.	June 5 » 15	174	15.5	—	17.8	28.2	3.4	24.7	1.7	1.2	6.9	.6[4]
53°25′ N., 178°24′ E.	June 26	170	33.5	—	10.0	35.4	.6	14.7	2.9	—	2.9	—
48°33′ N., 172°16′ E. 49°35′ N., 171°46′ E.	June 15 July 6	169	20.1	—	8.3	42.6	—	9.5	9.5	.6	8.8	.6[4]
MV *Mitkof*:												
50°51′ N., 175°00′ E.	June 15 » 16	64	25.0	12.5	6.3	35.9	—	10.9	1.6	—	3.1	4.7[5]
53°58′ N., 180°	July 6 » 11	14	28.6	14.3	—	28.6	—	21.4	—	—	7.1	—
MV *Tordenskjold*:												
56°00′ N., 170°00′ W.	June 20	294	56.2	—	10.5	25.2	—	7.5	—	—	.3	.3[6]

[1] Includes all fish that were aged.

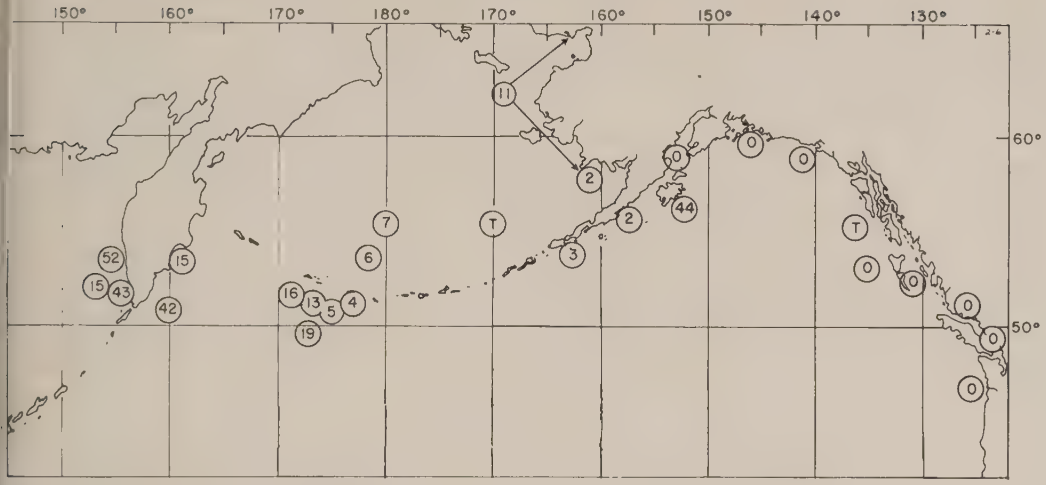
[2] Total percentage of 5_4, 6_2, 6_4, 7_3, 7_4 and 8_4 age groups.

[3] Age group 8_4.

[4] Age group 4_1.

[5] Age group 3_2.

[6] Age group 5_1.


150°
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52
15
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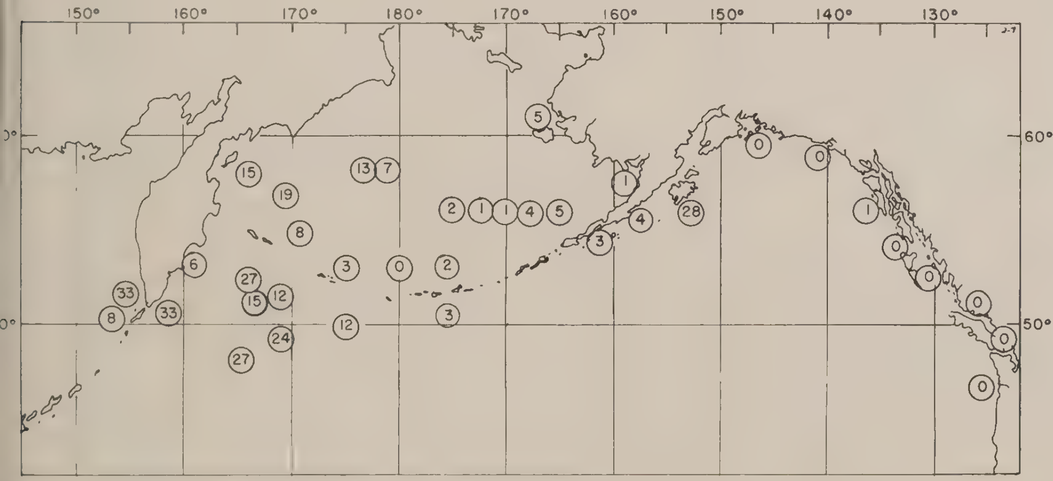
43
42
16
13
5
4
19

E 6. Percentages of fish of age groups 5_4, 6_2, 6_4 and older in samples from the North Pacific—Bering Sea areas, -May to mid-July, 1956. T indicates less than 0.5 percent.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8
2
1
1
4
5
6
3
0
2
27
15
12
33
8
33
24
12
3
27

RE 7. Percentages of fish of age groups 5_4, 6_2, 6_4 and older in samples from the North Pacific—Bering Sea areas, d-May to mid-July, 1957.

nation of the age of the fish is essential to a study of the scales, we should examine the nposition of the offshore samples in relation to of those taken inshore for any indications of ntal origin that might be evident.

90 to 100 percent of all fish caught in most xcept in Asia and Karluk River on Kodiak and an occasional sample from the Far North he 4_2, 5_2, 5_3 and 6_3 age groups, it is difficult, ur present samples, to derive reliable evidence inental origin from the occurrence of these groups alone. A few age groups, however, ewhat as biological tags: the 5_4, 6_2, 6_4, 7_3, 7_4, 8_5 fish, which occur more often in the Asian areas and in Karluk River than in Bristol Bay or elsewhere.

Tables 3 and 4 for 1956 and Tables 5 and 6 for 1957 show the age composition of the inshore and offshore samples for each of the two seasons, 1956 and 1957.

The combined percentages of fish of seven age groups, 5_4, 6_2, 6_4, 7_3, 7_4, 8_4 and 8_5, occurring in the inshore and high-seas samples taken in 1956 and 1957 are shown in Figures 6 and 7. These percentages show that fish of these seven age groups occurred with relatively higher frequency among fish taken near the Asian coast than among fish taken in the

TABLE 5. Percentage age composition of red salmon, collected in inshore areas, 1957.

Locality	Percent in age group														
	3_2	4_1	4_2	4_3	5_2	5_3	5_4	6_2	6_3	6_4	7_2	7_3	7_4	7_5	8_5
Bolshaya River[1]	—	—	—	—	40.0	6.7	—	6.7	20.0	20.0	—	3.3	3.3	—	—
Kamchatka River[1]	—	—	—	—	26.1	13.0	—	—	54.4	2.2	—	4.3	—	—	—
Okhotsk Sea	—	—	10.8	—	39.5	10.8	—	1.0	30.7	4.2	.2	.6	2.2	—	—
Eastern Kamchatka	—	.1	.3	—	15.8	7.5	—	.4	43.8	14.4	—	.7	16.6	.3	.1
Bristol Bay	—	—	4.6	.1	36.9	11.1	—	—	46.5	.1	—	—	.7	—	—
Far North	—	—	—	—	69.2	—	—	1.0	25.9	—	—	1.0	2.9	—	—
Kodiak Island	—	—	.9	1.2	13.3	40.9	.7	—	15.9	22.0	—	—	4.9	.2	—
King Cove	—	—	5.9	—	38.8	30.6	—	—	22.3	.6	—	.6	1.2	—	—
Chignik River	—	—	—	—	38.4	8.9	—	.6	49.1	.6	—	1.2	1.2	—	—
Copper River	—	.6	17.6	—	69.6	.6	—	—	11.6	—	—	—	—	—	—
Yakutat	—	—	6.4	1.8	27.5	56.1	—	—	8.2	—	—	—	—	—	—
Southeastern Alaska	1.2	.5	4.2	2.2	52.7	19.9	—	.3	18.4	.3	—	.3	—	—	—
Nass River	—	—	14.1	—	25.9	56.5	—	—	3.5	—	—	—	—	—	—
Skeena River	3.3	—	58.5	—	33.7	3.9	—	—	.6	—	—	—	—	—	—
Rivers Inlet	—	—	38.0	—	58.2	2.5	—	—	1.3	—	—	—	—	—	—
Fraser River	1.1	—	89.3	.6	7.9	1.1	—	—	—	—	—	—	—	—	—
Columbia River	20.3	—	62.1	2.7	2.7	12.2	—	—	—	—	—	—	—	—	—
TOTAL															

---

[1] Scale samples only.

North American areas, excepting Karluk River and the Far North.

Because these age groups occurred in both North America and Asia, and because there was a considerable range in the percentages of these age groups in the Asian coastal samples and in the samples from Karluk River and the Far North, it was not possible to make a satisfactory determination of the limits of distribution of North American and Asian salmon in the high seas, or to obtain satisfactory estimates of the proportions of North American and Asian salmon in the high-seas samples.

The samples taken on the high seas show that the percentages of fish of the seven age groups generally diminished from west to east in both years. This suggests that the relative abundance of red salmon of Asian origin diminished with increasing distance from the Asian coast. Salmon from the two continents possibly intermingled over a broad area.

ORIGIN INDICATED BY SCALE CHARACTERS

Selection of racial standards. On the American side of the Pacific Ocean and Bering Sea, Bristol Bay streams are unquestionably the major producers of red salmon west of longitude 135°W. Bering Sea streams other than the five major Bristol Bay rivers provide only nominal production. Rivers to the north of Bristol Bay (the Kuskokwim, Yukon and Norton Sound areas) and the Aleutian Island a negligible red salmon production when con with the major Bristol Bay producers (Atl 1955).

Bear and Sandy Rivers near the tip of the Peninsula are considered the best of these other They were surveyed in a number of years sinc and during this period the escapement for eac varied from about 100,000 to 200,000 sp (Thorsteinson, 1955; Calkins, 1958).

Production records indicate that runs of red to Gulf of Alaska areas west of longitude including Kodiak Island, Chignik and Cook are much smaller than those to Bristol Bay (I 1958 and 1959).

Because of their proximity to the Bering S North Pacific Ocean and their history of prod it appears reasonable to conclude that Brist rivers produce most of the North Americ salmon occurring in the Bering Sea-central Al area. This conclusion is supported by tagging The Fisheries Research Institute, University of ington, under contract to the U.S. Bureau o mercial Fisheries, and research vessels of the Ja Government carried on tagging studies durin and 1957.

Recoveries of red salmon tagged and release Attu Island to Unimak Island in 1956 and 19

ABLE 6. Percentage age composition of red salmon collected on the high seas, by vessel and locality, 1957.

nd locality	Date	Number of fish	Percent in age group										Total percent older ages[1]
			4_2	4_3	5_2	5_3	5_4	6_2	6_3	6_4	7_4	Other	
an-maru :													
., 164°05′ E.	May 18	78	—	—	19.2	1.3	—	—	52.6	17.9	9.0	—	26.9
-maru :													
., 167°22′ E.	» 19												
., 167°40′ E.	» 21												
an-maru :													
., 168°27′ E.	» 25	119	.8	—	24.4	10.9	—	.8	52.2	6.7	3.4	.8[2]	11.7
., 169°02′ E.	» 21												
., 169°55′ E.	» 27												
., 167°25′ E.	» 31	83	4.8	—	14.5	19.3	—	—	37.3	14.5	9.6	—	24.1
-maru :													
., 171°00′ E.	June 1												
., 175°02′ E.	» 6	162	3.7	14.8	14.8	18.5	2.5	—	18.5	3.1	6.2	17.9[3]	12.4
er :													
N., 175°00′ E.	» 10												
N., 175°00′ E.	» 11												
N., 175°00′ E.	» 12												
igh-seas fishery :													
N., 166°04′ E.	» 20	85	—	—	16.5	3.5	—	1.2	53.0	12.9	12.9	—	27.0
N., 179°10′ E.	» 27	59	1.7	—	50.8	13.6	—	—	27.1	—	6.8	—	6.8
N., 167°27′ E.	» 28	33	—	—	30.3	21.2	—	—	33.3	9.1	6.1	—	15.2
N., 177°17′ E.	July 1	39	2.6	—	33.3	2.6	—	—	48.7	—	12.8	—	12.8
N., 170°24′ E.	» 6	36	—	—	38.9	13.9	—	—	38.9	2.7	5.6	—	8.3
N., 169°11′ E.	» 12	31	3.2	—	25.8	3.2	—	—	48.4	3.2	16.2	—	19.4
N., 167°27′ E.	» 13	80	1.2	—	40.0	6.3	—	—	37.5	2.5	11.3	1.2[4]	15.0
N., 166°48′ E.	» 15												
eer :													
N., 175°00′ E.	June 14	58	6.9	12.1	12.1	32.8	3.4	—	22.4	-		10.3[5]	3.4
N., 175°00′ E.	» 20												
N., 180°	» 22	45	15.6	—	33.3	26.7	—	—	24.4	—	—	—	.0
N., 175°00′ W.	» 29	227	2.2	—	50.2	23.4	—	—	22.5	.4	.9	.4[6]	1.7
N., 175°00′ W.	» 30												
:													
N., 175°00′ W.	» 15												
N., 175°00′ W.	» 8	151	4.6	.7	35.1	43.7	—	—	13.2	1.3	.7	.7[7]	2.0
N., 175°03′ W.	» 9												
N., 175°00′ W.	» 10												
eer :													
N., 175°00′ W.	July 3–6												
:													
N., 173°00′ W.	June 17	141	2.1	—	56.7	22.0	—	—	17.8	—	.7	.7[8]	.7
N., 170°00′ W.	» 18	159	3.8	—	50.3	22.0	—	—	22.7	.6	.6	—	1.2
N., 170°00′ W.	» 19												
N., 170°00′ W.	» 20												
N., 168°00′ W.	» 21	58	8.6	—	36.2	34.5	—	—	17.2	—	3.5	—	3.5
N., 166°00′ W.	» 22	105	8.6	—	38.1	31.4	—	—	17.1	2.9	1.9	—	4.8
N., 166°00′ W.	» 23												
N., 166°00′ W.	» 24												
N., 165°00′ W.	July 10												
N., 175°00′ W.	May 28–31	61	36.1	3.3	3.3	45.9	—	—	3.3	1.6	1.6	4.9[9]	3.2
neer :													
N., 176°00′ W.	July 8												

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bined total percentage of ages 5_4, 6_2, 6_4, 6_5, 7_3, 7_4, 7_5 and 8_4. See Fig. 7.

group 7_5.

1.9) (3_1, 0.6) (3_2, 14.8) (6_5, 0.6) total 17.9.

group 7_3.

1.7) (3_2, 8.6) total 10.3.

group 8_4.

group 3_1.

group 4_1.

3.3) (4_1, 1.6) total 4.9.

been made only in Bristol Bay streams and on the high seas in the Bering Sea-central North Pacific area, with the exception of one fish tagged near Unalaska Island and recovered at Chignik (International North Pacific Fisheries Commission, 1958).

These recoveries of tagged red salmon differ from those of other species of salmon. Chum salmon tagged in the same area were recovered from Japanese, Okhotsk Sea, Kamchatka, Kuskokwim, Norton Sound and southeastern Alaska streams. Of a total of only 12 king salmon tagged in 1956 near Adak Island, one was recovered in the Salmon River, Idaho. From the 1957 tagging of pink salmon in the area from Attu Island to Unimak Island, recoveries were made only from Kamchatka streams and the offshore Bering Sea-central North Pacific areas. Four silver salmon tagged south of Atka Island were recovered near the Kamchatka River. One of seven steelhead tagged south of Atka Island was recovered in the State of Washington. (International North Pacific Fisheries Commission, 1957–1959.)

These results indicate that had red salmon from stocks east of the Alaska Peninsula been present in the tagged population in 1956 and 1957 some recoveries should have been made from that area.

On the Asian side of the Pacific and Bering Sea we know that the Ozernaya River, which empties into the Okhotsk Sea near the southwestern tip of the Kamchatka Peninsula, and the Kamchatka River, which empties into the Bering Sea about half way up the Peninsula, contribute the bulk of the red salmon production. Other streams such as the Bolshaya, Kukhtui, Pylga, and Paratunka Rivers also provide some red salmon production (Krogius, 1958); but they are of minor importance in relation to the Ozernaya River.

The runs to the Kamchatka River and more northerly rivers are considered to be early runs (from the end of May through June), while those to the Okhotsk Sea are later (from July into August). The migration pattern, as found from tagging by Japanese agencies in the period before 1953, indicates an area off the southeastern coast of the Kamchatka Peninsula where fish going north to the Kamchatka and other rivers and into the Okhotsk Sea could be taken (Fisheries Agency of Japan, 1955). By sampling this area and the Okhotsk Sea we could expect to obtain adequate samples of Asian fish without our having access to the Asian streams.

On the basis of the available information, samples from the Okhotsk Sea and off the southeastern coast of Kamchatka were used to represent the st Asian population of red salmon occurring Bering Sea-central North Pacific area. The st North American population of red salmon oc in this area was represented by samples taken pally from Bristol Bay rivers. Because 4-yea water age groups rarely occur in Bristol B North American standard was augmented by s of these age groups from Karluk River, Red southeastern Alaska, the Far North, Chignik and the Alaska Peninsula. The bulk of the fresh-water fish were taken in the Karluk Riv

Since nearly all of the fish used in the North can standard were taken from western Alask referred to as the Western Alaska standard following sections.

Selection of scale characters. The frequency distri of the circuli counts and scale measurements i growth zone were compared for the fish com the two continental standards. On the basis o comparisons the numbers of circuli in the first and total fresh-water zones were selected for de ing a classificatory procedure to determine the nental origin of the 2-year and 3-year fresh age groups taken on the high seas in 1956 and For the 4-year fresh-water age groups, the s the same two growth zones were selected.

Statistical comparisons of the means and va of the characters selected indicated that the d the two sexes could be combined for this stu

The characters selected for this study proba not the only ones that could be useful in sep continental stocks of salmon. A search for characters is being conducted. In addition, a samples are accumulated, the sources of va within the standard populations are being stu

Classification procedures. Bivariate frequency butions of the selected characters were tabula each population standard for each of the three water age groups: 2-year, 3-year and 4- Tables 7, 8 and 9 (Asian standard) and Tables and 12 (Western Alaska standard) show these t tions for the three fresh-water age groups. each of these tabulations a relative frequency bution was computed by dividing the number i cell by the total sample size for that tabulation each fresh-water age, the charts for the two sta were then superimposed so that for each ch combination the relative frequencies could be com (as an example, Table 13 provides such a comp for the 3-year fresh-water group).

'. Bivariate frequency distribution for Asian samples, 2-year fresh-water fish, 1957. (Frequencies of number of fish .ted by number of circuli in first ocean zone against number in fresh-water zone[1].)

	Circuli in first ocean zone																				Total fish
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
												1				2					3
							1						1	1	2	1					6
							1				1	5			1						8
							1	4		2		5	4	3	3			1			23
							2		2	9	4	5	4	2	2		2				32
						2	2	1	3	6	8	5	4	4	1						36
							2	3	4	5	11	9	6	1	1		2				44
						1	3	4	2	4	9	11	6	5	2					1	48
						2	6	6	4	4	4	3	5	1	2	1					38
				1	1		2	5	5	6	1	9	4	4	2	1					41
					1		3	3		3	3	2		2	1			1			19
						1	1	1	2	4		1	3	2							15
						1			2	2	3	1	1	1	4						15
					1		1	1	1		2	6	2	4							18
	1						1		1	2	1	2	1								9
										1			3	2							6
					1									1							2
							1														1
h	1			1	4	7	27	28	26	48	47	65	44	33	21	5	4	2		1	364

[1] udes intermediate growth, if any.

8. Bivariate frequency distribution for Asian samples, 3-year fresh-water fish, 1957. (Frequencies of numbers of fish lated by number of circuli in first ocean zone against number in fresh-water zone[1].)

	Circuli in first ocean zone																	Total fish
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
						1			1	1	1							4
					3	1	1			1	1							7
				1	3	1	4	3		2	1	3	1					19
				1	2	6		2	2	4	3	1						21
				1	2	3	8	8	6	12	4	2	1	1				48
					1	7	10	12	19	9	7	5	2	2				74
				1	5	7	18	15	19	19	12	8	3			1		108
				1	1	7	10	14	11	9	4	4	2	4	1			68
					4	5	8	8	14	11	5	9	2	2			1	69
						3	6	8	10	8	8	3	2		1			49
			1			1	4	6	7	2	7	4	3					35
					1	2	1	5	1	3	4	3	1				1	22
		1						1	3	3	2	4			1			15
					1			1			2	2		1				7
						1		1	1	1		4	2					10
	1					1			2		1							5
							2	1		1			2					6
									1			1						2
				1														1
										1								1
							1											1
sh	1	1	1	6	23	46	73	85	97	87	62	53	21	10	3	1	2	572

[1] udes intermediate growth, if any.

TABLE 9. Bivariate frequency distribution for Asian samples, 4-year fresh-water fish, 1957. (Frequencies of numbers of tabulated by width of first ocean zone in millimeters of projected image (magnification 42.5 times) tabulated against w of fresh-water zone[1].)

	Width of first ocean zone																											
Width of fresh-water zone	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
15																												
16																												
17																			1									
18											1		1															
19																												
20										1	1					2				1								
21											2	1				1		1		1								
22							2	1			1	2	1	3	5	2	1		1	1	2	2						
23									3	1	1	1	3	1	3	2	4	1		1	1		1					
24				1				4	1	5		4	3	4	4	5	6	4	3	1	1	2	1		3			
25									4	2	3	6	4	6	3	7	3	5		1	4	1			1	1		
26							1			2		2	3	3	5	4	2	4		1	1	1	1	2		1		
27										1			2	1	1		2	2	2	1	1		1	2	1	1		
28							1					1				2	1	3		2		1		1				2
29														1			1	2		1								
30											1																	
31																												
32						1																						
33									1																			
34																												
35																												
36																												
37																												
38																												
39																												
40																												
Total fish				1		1	4	5	9	12	10	17	17	19	21	25	20	22	7	11	10	7	4	5	5	3		2

[1] Includes intermediate growth, if any.

It is obvious from visual examination that certain cells in the charts represent combinations of characters which contain only fish from one or the other continental group. In other cells, especially near the middle of the distribution, fish from both continents occur.

These tables can be used alone to determine the most probable origin of an unknown fish by noting which continent has the higher relative frequency for the cell in which the characters of the unknown fish fall. But for convenience, an additional chart for each fresh-water age was made in which the standard with the higher relative frequency is indicated for each cell; N for Western Alaska and A for Asia.

These continental determination charts are shown as Tables 14, 15 and 16 for the 2-year, 3-year and 4-year fresh-water ages, respectively.

It should be pointed out that there were some cells on the charts for which there were no fish in either continental standard. In these cases, the cells marked N′ or A′ depending on whether the adj cells on the vertical axis were marked N or A some instances, the decision to mark a cell N′ was also influenced by the marking of the ad cells on the horizontal axis. Where it was not ble to make a decision, the cell was marked doubtful. The classificatory errors introduce arbitrarily marking a cell N′ or A′ are being ass

The two characters of the fish from an unk area are used to select the proper cell on the a priate chart. The cell then shows whether particular combination of characters occurs w greater percentage frequency in the Western A standard population or in the Asian standard lation. The fish is assigned accordingly.

Accuracy of classification procedures. A measure errors of misclassification inherent in the classifi procedure was obtained by classifying the fish prising the continental standard populations.

10. Bivariate frequency distribution for western Alaska samples, 2-year fresh-water fish, 1957. (Frequencies of numbers tabulated by number of circuli in first ocean zone against number in fresh-water zone[1].)

	Circuli in first ocean zone																	Total fish
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
					1													1
			1						1									2
					1			2										3
						2	2	1	1									6
				2	3	4	3	2	1									15
		1		6	12	9	7	3	2									40
			3	5	17	20	12	6										63
		2	5	14	11	21	22	5	3	1	2							86
		1	9	12	16	17	7	6	1	2								71
			2	6	8	10	13	8	4	2		1						54
		3	7	4	10	10	2	2	1									39
		1	1	3	2	5	2											14
	1			3		2												6
							1											1
h	1	8	28	55	81	100	71	35	14	5	2	1						401

ides intermediate growth, if any.

11. Bivariate frequency distribution of western Alaska samples, 3-year fresh-water fish, 1957. (Frequencies of numbers sh tabulated by number of circuli in first ocean zone against number in fresh-water zone[1].)

	Circuli in first ocean zone																Total fish
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
								1									1
												1					1
							2										2
					1	4	2	1	1								9
			2	3	2	3	2	8	5	2	1						28
		2	1	8	9	15	5	9	2	7	2						60
		2	4	4	14	15	16	18	14	5	2	1					95
		1		7	16	12	14	13	13	7	3						86
	1		3	7	15	16	23	23	13	2	2			1			106
		1	4	13	12	16	15	7	5	5	2						80
		1	2	6	9	6	11	8	6	5	1						55
		1	1	2	2	3	7	3	2	2							23
				1	2	1	2	1	1								8
			1	1				1									3
						2											2
h	1	8	18	52	82	93	99	93	62	35	13	2		1			559

ides intermediate growth, if any.

Table 12. Bivariate frequency distribution of western Alaska samples, 4-year fresh-water fish, 1957. (Frequencies of num of fish tabulated by the size of the first ocean zone in millimeters of projected image (magnification 42.5 times) tabu against the width of the fresh-water zone[1].)

Width of fresh-water zone	Width of first ocean zone																									
	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
15																										
16																										
17																										
18																										
19																										
20																										
21															1											
22																										
23							1					1						1								
24							1							1		1										
25					1		1		1	2		2					1									
26				1				1	1	1		1	2	1		2	2		1			1				
27										1			2	2	2				2	2						
28										2			2	2	2	2		1								
29									1	1		2	1		1	2		1	1	2	1	1				
30	1									1		2	2		2	2		1	1	2	2					
31							1		1	1					1	2			2	1		1				
32										1																
33												1		1		1										
34								1		1																
35					1																					
36																										
37																										
38															1											
39												1														
40																										
Total fish	1			1	2		4	2	4	11		10	9	7	10	12	3	4	7	7	3	3				

[1] Includes intermediate growth, if any.

The Asian continental standard was composed of 1,140 fish taken in 12 samples—three from the Okhotsk Sea and nine from the area off the southeastern coast of Kamchatka in 1957 (Table 17). Of the 1,140 fish, 973 were correctly classified as Asian fish and 167 were misclassified as American fish. This is an accuracy of 85.4 percent (error, 14.6 percent). Individual sample accuracy varied from 78.2 to 95.1 percent with most of the values falling between 86 and 94 percent. Sample sizes varied from 41 to 179 fish. The unweighted average error of classification for the 12 samples was 13.0 percent.

The Western Alaska standard population was composed of 1,077 fish taken in 1957. Bristol Bay rivers provided 981 fish; the remaining 96 fish were 4-year fresh-water fish taken principally from Karluk River. Of the 1,077 fish in the Western Alaska standard, 964 were correctly classified and 113 were misclassified. This is an accuracy of 89.5 percent (error, 10.5 percent). Individual sample sizes from eight to 139, and accuracy varied from 100 percent, with 10 out of 15 of the values than 89 percent. The unweighted average e classification for the Western Alaska samples w percent.

The average of the two unweighted average of classification was 13.7 percent (accuracy, 86 cent). By fresh-water age groups, the average were 14.1 percent for the 2-year group, 10.3 for the 3-year group, and 14.5 percent for the group.

The problem of checking the accuracy of timates of errors of classification is under con study. The most promising approach to the p appears to be the classification of samples of fis the same areas as the standards, but which w used to develop the classification procedure.

3. Relation between circulus counts in 3-year-old, fresh-water fish of Asian (in italics) and American origin, 1957.
ts limited to fresh-water and first ocean zones; based on Tables 8 and 11.)

Circuli in first ocean zone																
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
					0017			*0017*	*0017*	*0017*						
				0052	*0017*	*0017*			*0017*	*0017*						
			0017	*0052*	*0017*	*0070*	*0052*		*0035*	*0017*	*0052*	*0017*				
			0017	*0035*	*0105*		*0035*	*0035*	*0070*	*0052*	*0017*					
			0017	*0035*	*0052*	*0140*	*0140* 0018	*0105*	*0210*	*0070*	*0035*	*0017*	*0017*			
				0017	*0122*	*0175*	*0210*	*0332*	*0157*	*0122*	*0087* 0018	*0035*	*0035*			
			0017	*0087*	*0122*	*0315* 0036	*0262*	*0332*	*0332*	*0210*	*0140*	*0052*			*0017*	
			0017	*0017* 0018	*0122* 0072	*0175* 0036	*0245* 0018	*0192* 0018	*0157*	*0070*	*0070*	*0035*	*0070*	*0017*		
		0036	0054	*0070* 0036	*0087* 0054	*0140* 0036	*0140* 0143	*0245* 0089	*0192* 0036	*0087* 0018	*0157*	*0035*	*0035*			*0017*
	0036	0018	0143	0161	*0052* 0268	*0105* 0089	*0140* 0161	*0175* 0036	*0140* 0125	*0140* 0036	*0052*	*0035*		*0017*		
	0036	*1017* 0072	0072	0050	*0017* 0268	*0070* 0268	*0105* 0322	*0122* 0250	*0035* 0089	*0122* 0036	*0070* 0018	*0052*				
	0018		0125	*0017* 0286	*0035* 0215	*0017* 0250	*0087* 0233	*0017* 0233	*0052* 0125	*0070* 0054	*0052*	*0017*				*0017*
0018	*0017*	0054	0125	0268	0286	0411	*0017* 0411	*0052* 0233	*0052* 0036	*0035* 0036	*0070*		0018	*0017*		
	0018	0072	0233	*0017* 0215	0286	0268	*0017* 0125	0089	0089	*0035* 0036	*0035*		*0017*			
	0018	0036	0107	0161	*0017* 0107	0197	*0017* 0143	*0017* 0107	*0017* 0089	0018	*0070*	*0035*				
0017	0018	0018	0036	0036	*0017* 0054	0125	0054	*0035* 0036	0036	*0017*						
			0018	0036	0018	*0035* 0036	*0017* 0018	0018	*0017*			*0035*				
		0018	0018				0018	*0017*			*0017*					
			0017		0036											
									0017							
						0017										

TABLE 14. Continental determination chart, 2-year fresh-water fish, 1957. [A, Asian; N, Western Alaska; D, Doub
A′ and N′, no fish (see text).]

Number of circuli in fresh-water zone	Number of circuli in first ocean zone																		
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
7												A				A			
8							A					A′	A	A	A	A			
9							A				A	A	A′	A′	A	A′			
10							A	A	A′	A	A′	A	A	A	A	A′	A	A	
11					N		A	A′	A	A	A	A	A	A	A	A′	A		
12					N′	A	A	A	A	A	A	A	A	A	A	A′	A′		
13					N′	D	A	A	A	A	A	A	A	A	A	A′	A		
14					N′	N	A	A	N	A	A	A	A	A	A	A′	A′		
15				N	N′	N	N	N	N	A	A	A	A	A	A	A	A′		
16				A	N	N	N	N	N	A	A	A	A	A	A	A	A′		
17				N	N	N	N	N	N	N	A	A	N	A	A	A′	A	A	
18				N	N	N	N	N	N	N	N	N	A	A	A′	A′			
19				N′	N	N	N	N	N	N	N	N	A	A	A				
20				N	N	N	N	N	N	N	A	A	A	A	A′				
21	A			N	N	N	N	N	N	A	A	A	A	A′					
22			N	N	D	N	N′	N	N′	A			A	A					
23					A				N					A					
24																			
25																			
26							A												
27																			

TABLE 15. Continental determination chart, 3-year fresh-water fish, 1957. [A, Asian; N, Western Alaska; D, Doubtful
and N′, no fish (see text).]

Number of circuli in fresh-water zone	Number of circuli in first ocean zone																
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
8																	
9																	
10							A	A′	A′	A	A	A	A′	A′			
11						A	A	A	A′	A′	A	A	A′	A′			
12					A	A	A	A	A	A′	A	A	A	A	A′		
13					A	A	A	A′	A	A	A	A	A	A′	A′		
14					A	A	A	A	A	A	A	A	A	A	A		
15					A′	A	A	A	A	A	A	A	A	A	A	A′	
16					A	A	A	A	A	A	A	A	A	A	A′	A′	A
17					A	N	A	A	A	A	A	A	A	A	A	A	A′
18				N	N	A	A	A	N	A	A	A	A	A	A	A′	A′
19			N	N	N	N	N	A	N	A	A	A	A	A	A′	A	A′
20			N	N	N	N	N	N	N	N	N	A	A	A	A′	A′	A′
21			N	N′	N	N	N	N	N	N	N	A	A	A	D	A′	A′
22		N	A	N	N	N	N	N	N	N	A	N	A	A′	N	A	A′
23		D	N	N	N	N	N	N	N	N	N	N	A	A′	A	A′	
24		D	N	N	N	N	N	N	N	N	N	N	A	A	A′		
25		A	N	N	N	N	N	N	N	N	N	A	A′	A′			
26				N′	N	N	N	N	N	N	A	A′	A′	A			
27				N	N	N′	N′	N′	N	A	A′	A′	A				
28					A		N	N′			A′	A′					
29								D			A						
30								A									

6. Continental determination chart, 4-year fresh-water fish, 1957. [A, Asian; N, Western Alaska; D, Doubtful; A′ ′, no fish (see text).]

Size of first ocean zone																										
31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
																		A								
										A	A′	A						A								
										A′	A′	A′						A′								
									A	A	A′	A′	A′	A′	A	A′	A′	A′	A							
									A′	A	A	A′	A′	A′	A	A′	A	A′	A							
						A	A	A′	A′	A	A	A	A	A	A	A	D	A	A	A	A					
						N	A′	A	A	A	N	A	A	A	A	A	N	A′	A	A	A′	A				
			A			N	A	A	A	A′	A	A	A	A	A	A	A	A	A	A	A	A	A′	A		
			D	N		N	D	A	N	A	A	A	A	A	A	A	A	A	A	A	A	A′	A′	A	A	
			N			A	N	N	N	A′	N	N	A	A	N	N	A	N	A	A	N	A	A	A′	A	
						A′	D	N′	N	D	D	N	N	N	N′	A	A	N	N	A	D	A	A	A	A	
						A	D	N′	N	D	A	N	N	N	N	A	A	N′	A	D	A	A′	A	A′	A′	A
						D	N′	N	N	D	N	N	A	N	N	A	N	N	N	N	N	D				
N						D	N′	N′	N	A	N	N	D	N	N	D	N	N	N	N	N′					
						N	N′	N	N	D	N′	N′	N′	N	N	N′	N′	N	N	N′	N					
					A		N′	D	N	N′	N′	N′	N′	N′	N′											
							D	A	N′	N′	N	N′	N	N′	N											
							N	D	N																	
				N																						
													N													
										N																

1e 1957 season, we have available a sample of ken from fish caught by the Japanese research Etsuzan-maru and the *Kano-maru* in the area ngitude 160°E. and latitude 50°31′N. where our Asian standard samples were taken. These ere supplied as plastic impressions by Japanese s Agency scientists, but were received too late de in the Asian standards.

ldition, the scale samples from the Bolshaya mchatka Rivers for 1957, itemized in Table 1, ssified to continent of origin by this method and vide a check on the accuracy of the technique.

results of allocating these fish to continent of ısing these bivariate charts are shown in the g table:

Vessel or locality	Determinations of origin			
	Asian	American	Total	Percentage of accuracy
JRV *Etsuzan-maru*	86	8	94	91.5
JRV *Kano-maru*	83	7	90	92.2
Bolshaya River	30	0	30	100.0
Kamchatka River	38	9	47	80.9
Total and percent	237	24	261	91.1[1]

[1] Unweighted.

These results (average accuracy of 91.1 percent; range, 80.9 to 100 percent) indicate that fish of known Asian origin (Bolshaya and Kamchatka Rivers) and assumed Asian origin (taken from coastal waters) are classified with a degree of accuracy similar to that attained for the fish used in the Asian standards.

TABLE 17. Determinations of origin and percentage of error for red salmon collected from inshore areas, 1957.

Locality	Date	Determinations of origin			
		Asian	Western Alaska	Total	Perce of
Asian:					
Okhotsk Sea:					
52°08′ N., 154°15′ E.	June 24	124	30	154	19
50°52′ N., 153°28′ E.	July 4	142	37	179	20
51°16′ N., 153°29′ E.	" 14	147	25	172	14
Southeastern Kamchatka:					
49°14′ N., 158°11′ E.	July 10	38	3	41	7
49°02′ N., 158°20′ E.	" 14	44	3	47	6
48°57′ N., 158°30′ E.	" 15	35	7	42	16
51°13′ N., 159°45′ E.	" 24	61	17	78	21
51°22′ N., 160°15′ E.	" 22	72	11	83	13
51°28′ N., 161°15′ E.	" 5	133	14	147	9
51°39′ N., 161°40′ E.	" 20	68	7	75	9
52°28′ N., 161°42′ E.	June 30	70	11	81	12
51°39′ N., 162°16′ E.	July 1	39	2	41	4
Total and percent		973	167	1,140	14
					13
Western Alaska:					
Ugashik		13	122	135	9
Egegik		8	131	139	5
Naknek	July 3	6	80	86	7
"	" 5	3	92	95	3
"	" 11	5	60	65	7
"	" 12	1	81	82	1
"	" 21	5	42	47	10
"	" 25	3	90	93	3
"	" 29	0	21	21	0
"	" 30	0	8	8	0
Total, Naknek		23	474	497	4
Kvichak	July 8	6	23	29	20
"	" 9	13	36	49	26
"	" 10	16	59	75	21
Total, Kvichak		35	118	153	22
Wood River		11	45	56	19
Karluk[2]		23	74	97	23
Total and percent		113	964	1,077	10
					14

SUMMARY

Total correct determinations	1,937
Total incorrect determinations	280
Percentage of accuracy	87.4
	86.5[1]

---

[1] Unweighted.

[2] Western Alaska 4-year fresh-water fish; also includes one fish each from Naknek River and Ketchikan, two from Red and three each from Kuskokwim River, Chignik River, and King Cove.

etermine whether the classification procedure ed from the 1957 data would provide a reason- curate separation of the fish in the high-seas s of 1956, I classified the fish taken from the d populations in 1956 (Table 18). Of 648 ish, 500 or 77.2 percent were correctly classified . Of 786 Bristol Bay fish, 647 or 82.3 percent orrectly classified to western Alaska.

average of the two unweighted average errors sification (23.6 percent for Asian fish and 17.7 t for Bristol Bay fish) was 20.7 percent for the amples from the areas representing the con- al standards. The corresponding value for the amples was 13.7 percent. The similarity of ercentages indicated that the classification pro- developed from the 1957 data provided a ably suitable method for classifying the high- amples taken in 1956.

As a check on the estimated error of classification (23.6 percent) for the Asian standard in 1956, I classified 286 Asian fish that were not included in the standard. These fish were taken from the Ozernaya, Bolshaya and Kamchatka Rivers in 1956 (Table 1).

For the Ozernaya River, 89 of 95 fish or 93.7 percent, for the Bolshaya River, 60 of 91 fish or 65.9 percent, and for the Kamchatka River, 64 of 100 fish or 64 percent, were correctly classified to continent of origin. The unweighted average error of classification for these samples was 25.5 percent—a percentage quite similar to the average error of classification for the Asian standard.

Classification of 1956 and 1957 high-seas samples to continent of origin. Using the classification procedure developed from the 1957 data, the fish taken in high-seas samples in 1957 and 1956 were classified to western Alaska or Asia (Tables 19 and 20, and Figures 8 and

TABLE 18. Determinations of origin and percentage of error for red salmon, 1956.

cality	Date	Determinations of origin			Percentage of error
		Asian	Western Alaska	Total	
an :					
khotsk Sea :					
51°49′ N., 154°06′ E.	June 21	88	29	117	24.9
52°08′ N., 154°32′ E.	» 28	119	36	155	23.2
51°55′ N., 154°13′ E.	July 6	137	43	180	23.9
51°22′ N., 153°51′ E.	» 13	37	15	52	28.8
outheastern Kamchatka :					
51°40′ N., 159°50′ E.	Sept. 5	119	25	144	17.4
otal and percent		500	148	648	22.8 23.6[1]
stern Alaska :					
gashik River		18	117	135	13.3
gegik River		15	156	171	8.8
aknek River		33	138	171	19.3
vichak River		48	108	156	30.8
ushagak River		25	128	153	16.3
otal and percent		139	647	786	17.7 17.7[1]

SUMMARY

Total correct determinations	1,147
Total incorrect determinations	287
Percentage of accuracy	80.0 79.3[1]

---

[1] nweighted.

TABLE 19. Continental origin of red salmon collected on the high seas, 1957.

Vessel and locality	Date	Number of determinations: Western Alaska	Number of determinations: Asian	Number of determinations: Total	Number of samples	Percentage western Alaska	Adj perce wes Alas
Etsuzan-maru:							
48°23′ N., 164°05′ E.	May 18	10	60	70	3	14.3	0
Kano-maru:							
48°02′ N., 167°22′ E.	May 19						
48°08′ N., 167°40′ E.	» 21						
Etsuzan-maru:							
52°31′ N., 168°27′ E.	May 25	41	76	117	3	35.0	29
51°15′ N., 169°02′ E.	» 21						
51°28′ N., 169°55′ E.	» 27						
49°02′ N., 167°25′ E.	» 31	15	59	74	2	20.3	8
Kano-maru:							
49°39′ N., 171°00′ E.	June 1						
49°55′ N., 175°02′ E.	» 6	53	96	149	4	35.6	30
MV *Pioneer*:							
50°00′ N., 175°00′ E.	June 10						
50°00′ N., 175°00′ E.	» 11						
50°00′ N., 175°00′ E.	» 12						
Japanese high-seas fishery:							
52°33′ N., 166°04′ E.	June 20	6	65	71	1	8.5	0
58°15′ N., 179°10′ E.	» 27	40	17	57	1	70.2	78
51°40′ N., 167°27′ E.	» 28	5	25	30	1	16.7	3
58°10′ N., 177°17′ E.	July 1	18	21	39	1	46.2	44
54°51′ N., 170°24′ E.	» 6	10	17	27	1	37.0	31
57°02′ N., 169°11′ E.	» 12	12	19	31	1	38.7	34
57°26′ N., 167°27′ E.	» 13	25	45	70	2	35.7	30
58°12′ N., 166°48′ E.	» 15						
MV *Pioneer*:							
53°00′ N., 175°00′ E.	June 14	36	20	56	2	64.3	69
53°00′ N., 175°00′ E.	» 20						
53°00′ N., 180°	» 22	30	14	44	1	68.2	75
56°00′ N., 175°00′ W.	June 29	190	30	220	3	86.4	100
56°00′ N., 175°00′ W.	» 30						
MV *Attu*:							
56°00′ N., 175°00′ W.	June 15						
53°00′ N., 175°00′ W.	» 8	121	22	143	4	84.6	98
53°00′ N., 175°03′ W.	» 9						
53°00′ N., 175°00′ W.	» 10						
MV *Pioneer*:							
53°00′ N., 175°00′ W.	July 3 to 6						
MV *Attu*:							
56°00′ N., 173°00′ W.	June 17	100	33	133	1	75.2	85
56°52′ N., 170°00′ W.	June 18	124	30	154	3	80.5	92
56°52′ N., 170°00′ W.	» 19						
56°00′ N., 170°00′ W.	» 20						
56°00′ N., 168°00′ W.	» 21	49	7	56	1	87.5	100
56°00′ N., 166°00′ W.	June 22	92	34	126	4	73.0	81
56°00′ N., 166°00′ W.	» 23						
55°00′ N., 166°00′ W.	» 24						
56°00′ N., 165°00′ W.	July 10						

Continue

TABLE 19. Continued.

essel and locality	Date	Number of determinations: Western Alaska	Number of determinations: Asian	Number of determinations: Total	Number of samples	Percentage western Alaska	Adjusted percentage western Alaska[1, 2]
00′ N., 175°00′ W.	May 28 to May 31	38	15	53	2	71.7	80.1
Pioneer :							
00′ N., 176°00′ W.	July 8						

ee Figure 8.

orrection formula :

$$F_a = \frac{K_a - P_b}{1 - (P_a + P_b)}$$

re

F_a = corrected proportion of western Alaska type fish.

P_a = misclassification error of western Alaska type fish (14%).

P_b = misclassification error of Asian type fish (14%).

$K_a = N_a/n$

ere

n = number in sample,

d

N_a = observed number western Alaska fish in sample.

Total sample" does not include fish that could be aged only.

In some cases, samples taken in the same general lity were combined.

o obtain estimates of the proportions of western ska type red salmon in the high-seas samples, it necessary to apply a correction for the errors of sification by the formulas shown in Tables 19 and

he errors of classification used for making the corions were 14 and 21 percent for the 1957 and 1956 ples, respectively. These errors were obtained by nding off the averages of the unweighted errors, and 20.7 percent, respectively.

t is recognized that the average errors of classifica- used in this study do not apply equally well to different fresh-water age groups, the two conntal standards, or to each component of the ndards. In addition, the average errors might not ly to fish which originated in areas not included in standard populations but which might have been sent in the high-seas samples.

n examination of the error or bias caused by using average errors of classification has not been comed. Thus, the classifications of the 1957 and 1956 h-seas samples should be considered as preliminary erminations.

n the basis of the high-seas samples taken in 1957, ppeared that western Alaska salmon predominated north of the Aleutian Chain from Alaska to the area between longitudes 175°E. and 178°E. Westward from this area, north of the Aleutians, Asian salmon appeared to predominate.

In the area south of the Aleutians, Asian salmon appeared to predominate eastward from Kamchatka to at least longitude 175°E. No samples were taken south of the Aleutians between longitudes 175°E. and 175°W. One sample taken at longitude 175°W., south of the Aleutians, indicated a predominance of western Alaska salmon in this locality.

Within the general area north of the Aleutians where western Alaska salmon appeared to predominate in 1957, only three samples were taken in 1956. These samples indicated a predominance of western Alaska salmon within that area in 1956 also. No samples were taken west of longitude 178°E. in the area north of the Aleutians in 1956.

Within the general area south of the Aleutians where Asian salmon appeared to predominate in 1957, five samples were taken in 1956. Four of these samples indicated a predominance of Asian salmon within that area in 1956 also. Western Alaska salmon predominated in the remaining sample.

The collection and analysis of additional samples, together with the completion of the studies mentioned previously, will permit further evaluation of the classifi-

TABLE 20. Continental origin of red salmon collected on the high seas in 1956.

Vessel and locality		Date	Number of determinations: Western Alaska	Asian	Total[1]	Number of samples	Percentage western Alaska	Ad perc we Ala
Japanese high-seas fishery:								
50°22′-30′ N.,	176°04′-07′ E.	May 25-28	81	49	130	2	62.3	7
52°08′ N.,	170°52′ E.	June 5	106	119	225	2	47.1	4
51°40′ N.,	170°58′ E.	» 15						
51°38′ N.,	173°38′ E.	June 5	77	83	160	2	48.1	4
51°56′ N.,	172°30′ E.	» 15						
53°25′ N.,	178°24′ E.	June 26	102	58	160	1	63.8	7
49°35′ N.,	171°46′ E.	July 6	25	87	112	2	22.3	
JRV *Takuyo-maru:*								
48°33′ N.,	172°16′ E.	June 15						
MV *Mitkof:*								
50°-51° N.,	175°00′ E.	June 15-16	30	34	64	2	46.9	4
53°-58° N.,	180°	July 6-11	8	6	14	4	57.1	6
MV *Tordenskjold:*								
56°00′ N.,	170°00′ W.	June 20	192	79	271	1	70.8	8

[1] Does not include fish that could be aged only.

[2] See Figure 9.

[3] Correction formula for adjustment

$$F_a = \frac{K_a - P_b}{1-(P_a+P_b)}$$

where F_a = corrected percentage of western Alaska type fish.

P_a = misclassification error of western Alaska type fish = 21 percent.

P_b = misclassification error of Asian type fish = 21 percent.

$$K_a = \frac{N_a}{n} = \frac{\text{number of western Alaska fish}}{\text{total (western Alaska + Asian fish)}}.$$

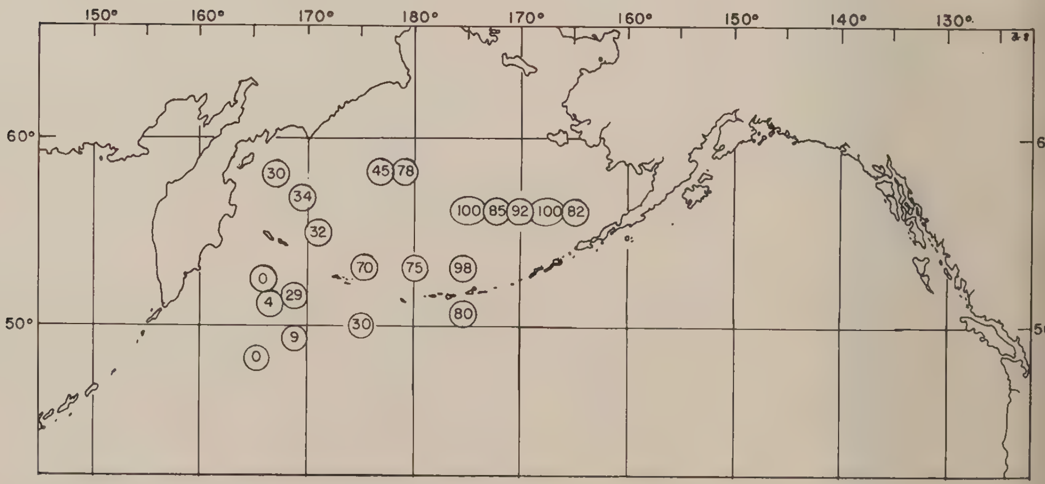
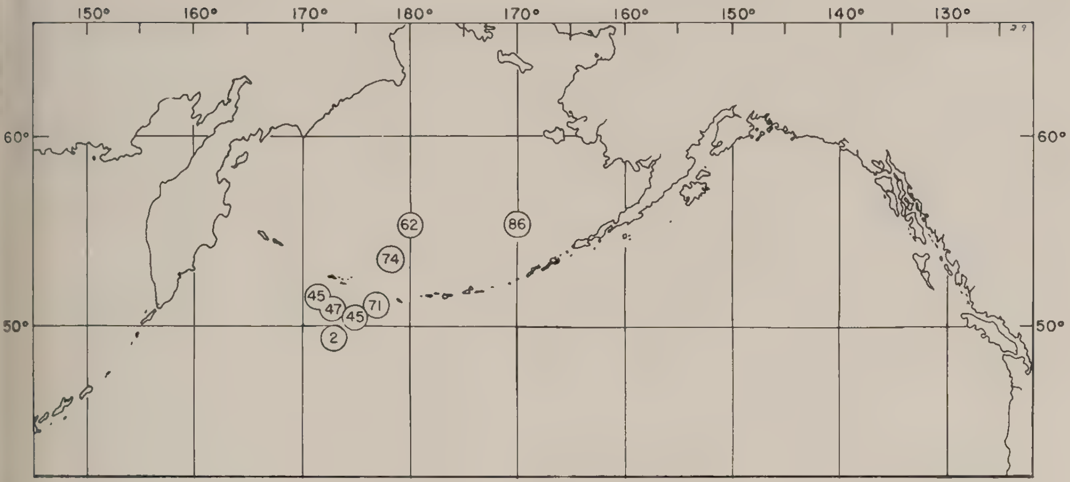


FIGURE 8. Adjusted percentage distribution of western Alaska type red salmon in samples from North Pacific—Bering areas, mid-May to mid-July, 1957.



IGURE 9. Adjusted percentage distribution of western Alaska type red salmon in samples from North Pacific—Bering Sea areas, mid-May to mid-July, 1956.

y procedures used in this paper and the accuracy ıe classifications of the 1956 and 1957 high-seas ples.

SUMMARY

wo methods of determining the continental origin d salmon in the central North Pacific-Bering Sea are described, and the results of applying these methods to the high-seas samples taken in the od May to July in 1956 and 1957 are presented.

he first method, applicable to groups of fish, zes the occurrence of fish of seven age groups, 5_2, 6_4, 7_3, 7_4, 8_4 and 8_5, as indicators of the pres- e of red salmon of Asian origin.

he second method utilizes a bivariate frequency ribution of the number of circuli in the total fresh- er zone and the first ocean zone for 2-year and 3- r fresh-water age groups, and the size of the same zones for 4-year fresh-water fish. This method mits the classification of individual fish to continent rigin.

pplication of the first method to the 1956 and 1957 ples of red salmon from the central Aleutian- ing Sea area for the season May to July indicates the relative abundance of red salmon of Asian in diminished with increasing distance from the n coast in those years. It is not possible to make tisfactory determination of the limits of distribution sian and North American red salmon on the high on the basis of the 1956 and 1957 age composition a.

Classification by the second method of fish in the high-seas samples of red salmon from the central Aleutian-Bering Sea area for the season May to July, 1957, indicates that western Alaska red salmon predominated north of the Aleutian Chain from Alaska to the area between longitudes 175°E. and 178°E. Westward from this area, north of the Aleutians, Asian salmon appeared to predominate from Kamchatka to at least longitude 175°E., and western Alaska salmon predominated in the one sample taken east of 175°E., at longitude 175°W.

Classification by the second method of fish in the samples from the central Aleutian-Bering Sea area for the season May to July, 1956, indicates that western Alaska red salmon predominated within the same general area, north of the Aleutians, in which they were predominant in 1957. Similarly, in 1956, Asian red salmon predominated within the same general area, south of the Aleutians, in which they were predominant in 1957.

The techniques used and the classificatory results presented in this paper are being evaluated by means of further studies and additional samples of fish.

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J. Morph., v. 113, no. 2, September.
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PRESS OF
THE WISTAR INSTITUTE
OF ANATOMY AND BIOLOGY
PHILADELPHIA, PA., U.S.A.

nted from JOURNAL OF MORPHOLOGY
l. 113, No. 2, September 1963

e Structure of the Eye of *Sardinops caerulea*, *graulis mordax*, and Four other lagic Marine Teleosts

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is clear from the extensive review of lls ('42) and from the work of many er investigators that there is consider- variation in the structure of the tele- eye, and that many of the specializa- ns are obvious adaptations to particular ironmental situations. The present dy was undertaken to find out what differences are in the eyes of certain agic marine teleosts. A knowledge of h differences will be useful in formu- ng hypotheses to be tested in experi- ntal studies of their behavior. The ies reported on here are the Pacific sar- e (*Sardinops caerulea*), the American d (*Alosa sapidissima*), the northern hovy (*Engraulis mordax*), the deep- lied anchovy (*Anchoa compressa*), the k mackerel (*Trachurus symmetricus*), the Pacific mackerel (*Pneumatophorus go*).[1]

This work was undertaken as a part of research program of the California operative Oceanic Fisheries Investiga- ns. The interest of this program for eral years has been centered on under- nding the causes of fluctuations in the undance and availability of the Pacific dine and certain of its ecological asso- tes in the California Current System. e northern anchovy, the jack mac- rel and the Pacific mackerel are eco- gical associates of primary interest. The erican shad and the deep-bodied an- ovy are included in this report to add rspective to the differences between the cific sardine and northern anchovy.

Dissections of the eye and the ocular gion of the head disclosed anatomical fferences among these six species that e suggestive of differences in the way e eye is used. The anatomical differences are in eye covering, ocular circulation, oculomotor musculature and lens suspension. Oculomotor musculature and lens suspension are of particular interest because they indicate the degree of eye mobility and the direction of the visual axis respectively. These features will be described briefly for each species.

Histological preparations of the retina revealed considerable differences among these species. The major differences are in the distribution and abundance of photoreceptor cells, the distribution and the abundance of certain secondary neurons, and the structural arranagement of pigment epithelium cells. These three features of the retina will be described in detail for each species and then compared in the discussion.

Differences in these features are the basis for a number of generalizations and much speculation on the differences in visual capacity among vertebrates. The accepted principles, and some of the current conjecture, are summarized and documented by Walls ('42) and Polyak ('57). Some of the major concepts, in so far as they pertain to the present study, may be summarized as follows: Visual acuity and sensitivity are known to vary with the spacing and arrangement of cones and rods, and abundance of these structures are frequently compared to indicate differences in visual capacity. The abundance of secondary neurons, such as horizontals, bipolars and ganglion cells, has also been observed to vary with visual capacity, so their numbers or simply the thickness of the layers they constitute in the retina are often compared to indicate differences in neural complexity or "differentiation," though generally not in any real quantitative sense.

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[1] Because of conflicting published opinions concerning the taxonomy of this species, it may be referred to under a variety of scientific names: *Pneumatophorus diego* (Ayres), *Pneumatophorus japonicus* (Houttuyn), *Scomber diego* Ayres, *Scomber japonicus* Houttuyn, *Scomber japonicus diego* Ayres.

The pigment epithelium cells and the photomechanical processes in which their movements are coordinated with those of the photoreceptors, exhibit specializations in some teleosts that would obviously lower the visual threshold and enhance visual sensitivity in dim light. Here again it is difficult to relate structural differences to visual function in anything but a subjective sense.

The descriptions and comparisons given in this report are in many ways based on differences in the number or size of various structures. Differences in number and size, when considered along with various other features, suggest the probability of certain functional differences, but the exact nature and true scale of such differences will depend on future experimental studies.

MATERIALS AND METHODS

Dissections and examinations of extraretinal features were made on specimens that had been fixed in 10% formalin. For histological preparations of retinae, specimens were killed and immediately enucleated. Before enucleation each eye was marked at two points on the cornea for orientation. The eyes were then fixed *in toto* in Bouin's fluid. After a minimum fixation period of 48 hours, retinae were removed from the eyes intact, dehydrated and cleared in normal butyl alcohol, and embedded in 54°–56° F rubber paraffin.

Two measurements, standard length and lens diameter, were recorded for all specimens from which histological preparations were made. Because the teleost eye is a proportionate structure, lens diameter is used throughout this report as an index of eye size. According to Walls ('42), Matthiessen had shown by measurements on numerous species that the distance from the center of the unaccommodated lens to the retina is always 2.55 times the radius (or 1.275 times the diameter) of the lens (Matthiessen's ratio).

The density distribution of cones was determined from tangential sections at
16 locations on the retina. Embe
retinae were cut into dorso-nasal, ve
nasal, dorso-temporal and ventro-tem
quarters (fig. 1), and each quarter
further divided into four approxim
equal triangular segments. Each of
16 segments was then re-embedded
sectioned at the center of its convex
face. Sections were mounted serially
unstained for phase microscopy. An
lar square with an area of 0.0064
was used as a unit area and all c
whose centers fell within its border
any particular count were recorded.
counts, each on alternate sections of
serial, were made from each segmer
a retina. Mean, minimum and maxi
numbers for each segment are given i
descriptions.

Counts of rod nuclei, horizontal, bip
amacrine and ganglion cells are give
the same specimens for which the
counts are given. In each case tange
sections were made from one eye fo
cone counts, and cross sections were
from the other eye for counts of the
ous neurons. The cross sections app
mately bisect the ventro-temporal qu
because the highest densities of cones
certain of the neurons occur in this
tion in the six species described, a
many other fishes. In the species
scribed here the optic cleft (fig. 1), w
results from incomplete closure of
embryonic fissure, lies entirely or al
entirely within the ventro-temporal
ter. The portion of the cross section n
of the optic cleft is referred to as the
arc and the portion temporad of the
is referred to as the temporal arc i
following descriptions.

In addition to the preparations for
and neuron density distributions, ta
tial sections were made from a seri
sardines to clarify the relation bet
cone density and eye size, and cross
tions were made from a series of nort
anchovies to clarify the photomecha
process. Such series were not mad
the other species because the addit
information would have been slight fo
considerable amount of work requ
Only for the Pacific mackerel were a
additional tangential preparations n
Cross sections, however, were made

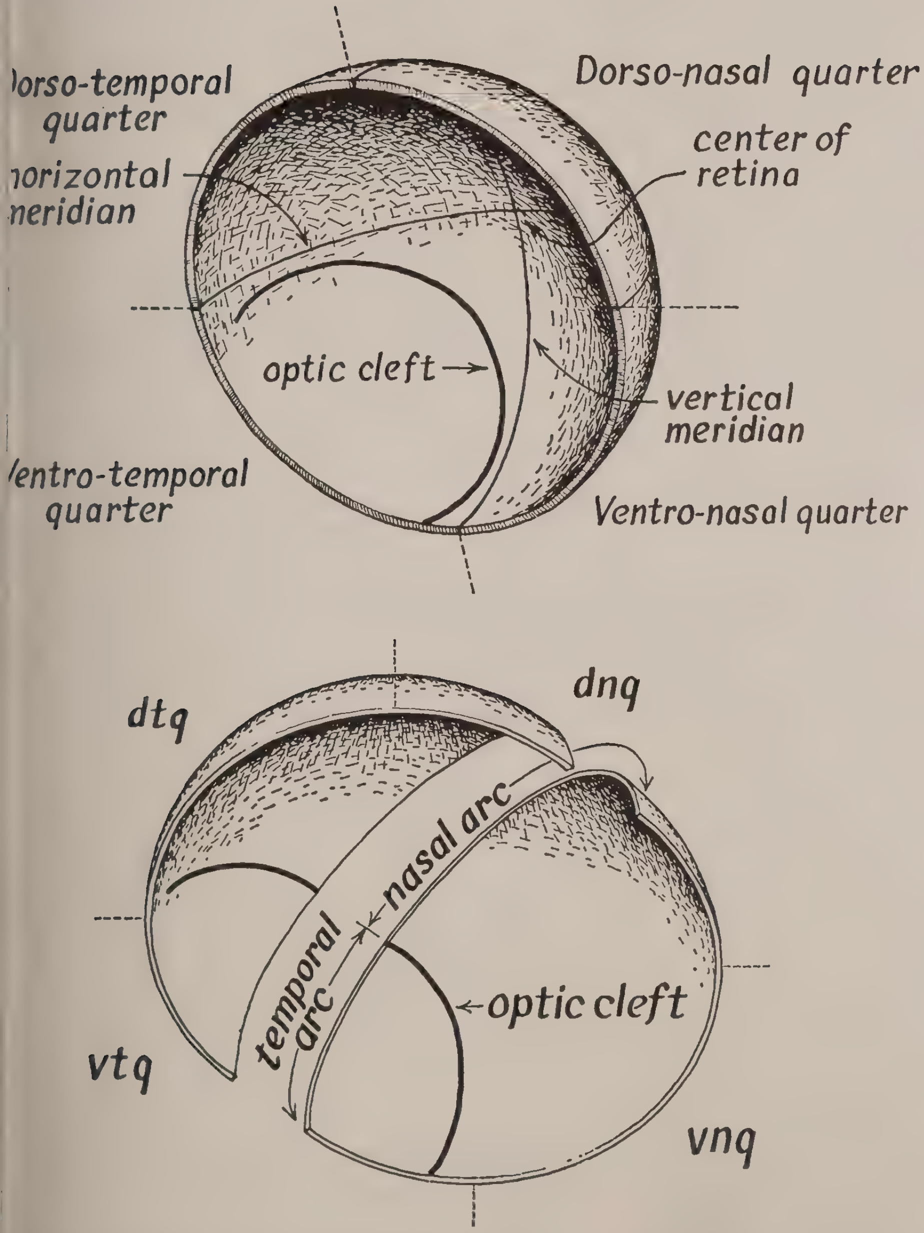

orso-temporal quarter
Dorso-nasal quarter
center of retina
orizontal
eridian
optic cleft
vertical meridian
entro-temporal quarter
Ventro-nasal quarter
dtq
dnq
nasal arc
temporal arc
optic cleft
vtq
vnq

Fig. 1 Perspective drawing of the retina of *Sardinops caerulea* showing the division into quar-s and the orientation of cross section preparations.

one or two dark-adapted specimens of each species, except for the shad. To produce the dark-adapted condition, specimens were placed in totally darkened tanks at least four hours prior to killing.

All cross section preparations were 8 to 10 μ in thickness. Many were mounted unstained for phase microscopy, but a good number were stained with hemalum and eosin or chlorazol black E to clarify certain structural details. In some preparations fuscin, the melanin-like pigment present in the pigment epithelium cells of the retina, was removed by bleaching the mounted and cleared sections in a 1% solution of hydrogen peroxide for 8 to 12 hours. In certain preparations it was also necessary to remove guanin crystals from the pigment epithelium cells. This was accomplished by immersing the mounted and cleared sections in a 0.2% aqueous solution of nitric acid and examining them at frequent intervals. Complete removal took several hours.

The stratification of the different kinds of cells in the retina is illustrated by a drawing of the nasal arc cross section of the sardine (fig. 2) in which the components of the photoreceptor cells as well as all layers of the retina are labeled. This stratification is typical of teleosts, differences being mainly in the abundance of various neuron types and the thickness of different layers. The different classes of neurons are quite distinctive and easily identified. The synaptic connections between the neurons are extremely complex and poorly understood. Polyak ('57) has done the most definitive work to date on this particular aspect of retinal structure. In the present study no attempt is made to delineate synaptic relationships. Comparisons are made entirely on the basis of estimated numbers of cells per unit area (0.0064 mm^2) of retinal surface.

Densities were estimated by the method of differential cell counting described by Trowell and Westgarth ('59). The number of each kind of nucleus, n, intersected or touched by a line running perpendicular to the plane of the retinal layers was counted at six locations near the centers of the nasal and temporal arcs. The sampling area of each kind of nucleus counted is $a = r(2t + \pi r)$, where r is the r of the nucleus and t the thickness c section. To make the densities compa to those obtained for cones by countin numbers in a particular unit area o nal surface, s^2, it is necessary to kno number of nuclei, N, under an ar Since $N = ns^2/a$ and $a = r(2t + \pi r)$, $ns^2/r(2t + \pi r)$.

One value of N, estimated in this is given for each kind of nucleus a centers of the nasal and temporal ar the following descriptions. Rods, inc tally, were estimated from the densi their nuclei in the outer nuclear laye cause the rods themselves in the v cell layer are too small and too h stratified to be counted.

SARDINOPS CAERULEA

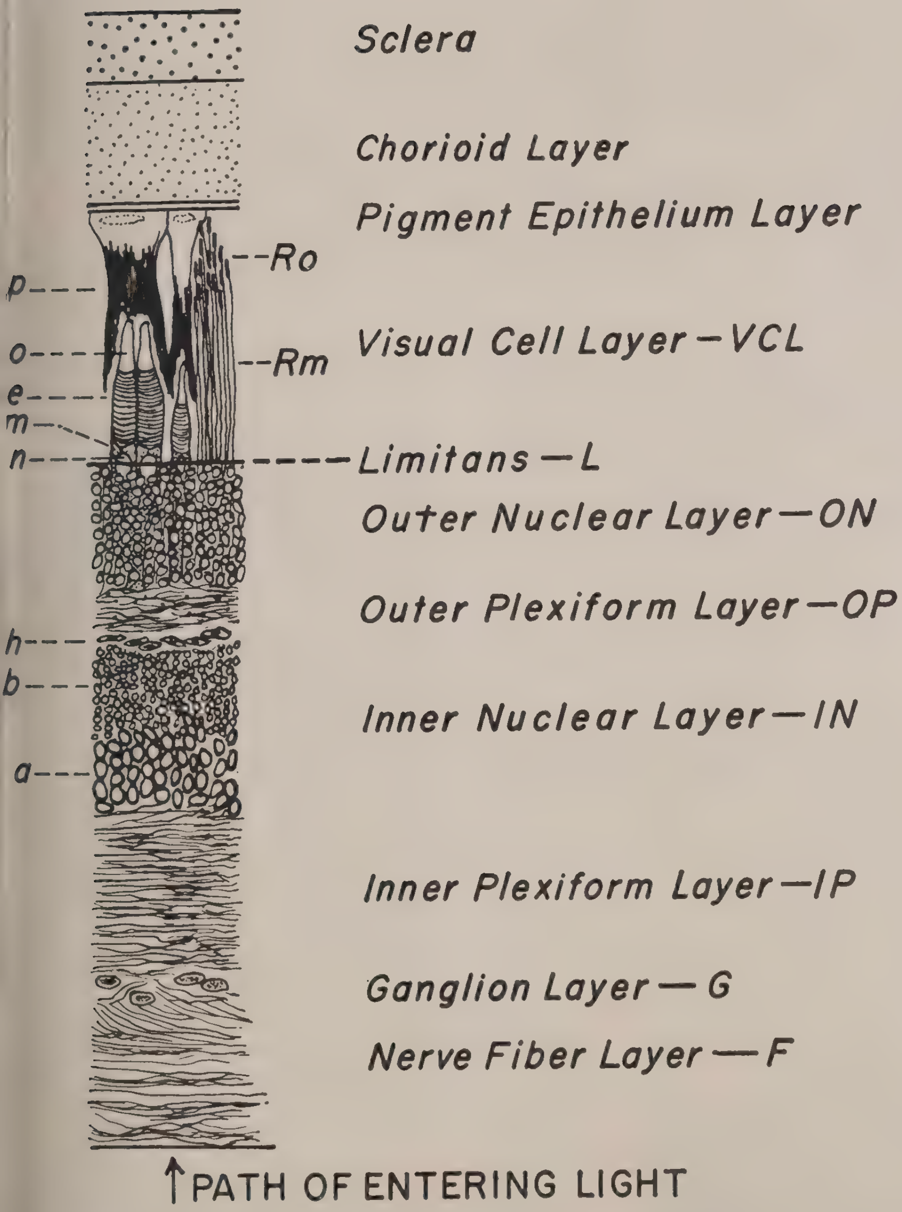
Extra-retinal features

The eye of the Pacific sardine, *Sard* *caerulea*, is partially covered by tran ent vertical lids. The transparency c lids and the integument between the and nostrils permit the visual fiel each eye to cross some distance in fro the snout. The function of the lids i of streamlining without reducing the scopic visual field (Walls, '42).

The six oculomotor muscles are al developed. They are inserted periph except the *anterior rectus*, which i serted close to the mesial center o eye.

The ocular circulation includes pseudobranch and a horseshoe-sh chorioid gland in the chorioid layer lying the retina. Although the ch layer is the primary organ of intrao circulation, a reduced falciform pr invaginates through the optic cleft to tion as a secondary organ of circula

The spherical lens, which prot partly through the pupil, is suspend a ligament that originates in the c zone dorsally and slightly behind the tical meridian of the eye. A retractor cle originates ventrally in the ciliary and inserts over the nasal surface o lens. When this muscle contracts lens moves inward and toward the ve temporal quarter of the retina.


Sclera
Chorioid Layer
Pigment Epithelium Layer
Ro
p
Visual Cell Layer — VCL
o
Rm
e
m
n
Limitans — L
Outer Nuclear Layer — ON
Outer Plexiform Layer — OP
h
b
Inner Nuclear Layer — IN
a
Inner Plexiform Layer — IP
Ganglion Layer — G
Nerve Fiber Layer — F
↑PATH OF ENTERING LIGHT

ig. 2 Cross section of the retina of *Sardinops caerulea* at the center of the nasal arc to show arrangement of layers. a. amacrines; b. bipolars; e. cone ellipsoid; h. horizontal cells; m. cone oid; n. cone nucleus; o. cone outer segment; p. extension of pigment epithelium cells; Rm. rod oid; Ro. rod outer segment.

The retina

Visual cell layer. The visual cell layer of the retina contains double cones,[2] single cones and rods as well as extensions of the pigment epithelium cells. Both cones and rods vary greatly in density distribution over the retina, and the cones also vary in size.

Figures 3 and 4 show the maximum, minimum and mean counts of double and single cones respectively in 16 segments of the retina. Figure 5 is a graphic interpre-

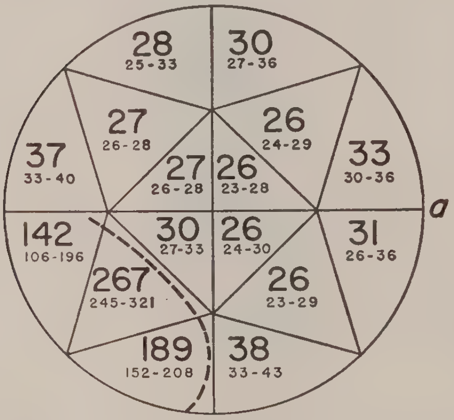


Fig. 3 *Sardinops caerulea.* The density of double cones in sixteen segments of the retina. The means are shown in large type, the ranges in small type. The dashed line indicates the optic cleft.

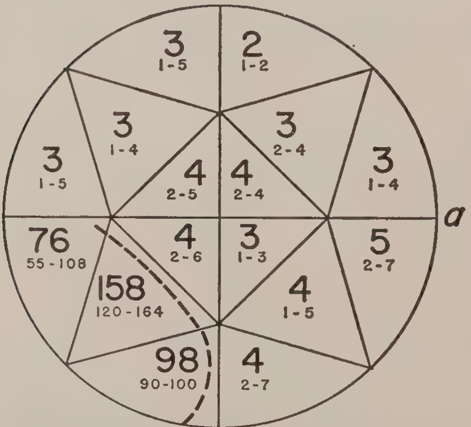


Fig. 4 *Sardinops caerulea.* The density of single cones in 16 segments of the retina.

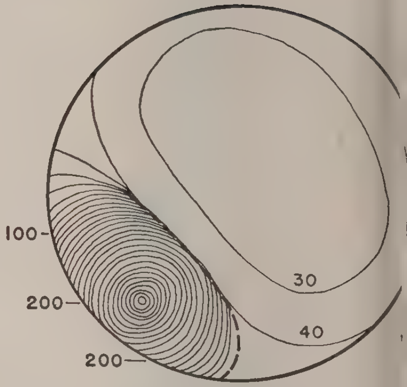


Fig. 5 *Sardinops caerulea.* The probab ble cone topography of the retina.

tation of the double cone density dis tion. The region of higher cone d delimited by the optic cleft in the v temporal quarter constitutes an *are poralis*, or zone of acute vision. Th sity distribution in the *area* suggest there is a maximum point or pl somewhere near its center, as indica figure 5. The presence of a foveal ture was not suggested by any c preparations examined.

Single cones are half as abunda the doubles in the *area temporalis*, t together forming a uniform mosaic p (fig. 24). In the nasal portion c retina, however, the double cone arranged in fairly regular rows wit gle cones occurring irregularly, p one to every five or ten double (fig. 23).

Cone measurements (table 1) ta the middle of the nasal and tempora are assumed to be representative nasal and temporal portions of the because cones are rather uniform i along each arc. They become noti smaller only near the periphery c retina.

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[2] Though the term double is now generally to all such cone types, whether they are logically symmetrical or asymmetrical, it sh noted that the double cones in the six spe scribed in this report are the symmetrical t viously known as twin cones. Lyall ('57b) c type an equal double cone. The recent use of for the symmetrical type has come about be number of investigators have found that halves often stain differently indicating th may not be the same functionally.

TABLE 1

Sardinops caerulea

andard length 154 mm, lens diameter 4.00 Cone measurements in microns at the mid- ts of the nasal arc (N) and temporal arc (T). r segment measurements are based on the soid. Myoid length is the distance between limitans and the inner end of the ellipsoid he light-adapted retina.

	N		T	
	Double cone	Single cone	Double cone	Single cone
er segment ngth	15	10	16	16
er segment ngth	18	13	12	12
er segment iameter	16	5	5	2
id length	0	0	7	7

The measurements, (also figs. 23, 24, -38), show that single cones are smaller n double cones in both regions and that h kinds of cones are more slender and ngated in the *area temporalis*, where mbers per unit area are high.

As is generally the case with fishes, eye e in the sardine increases proportion- ly to body length, and this raises the estion of whether cone density in the ina changes as the eye grows. If so, would be desirable to know how the ne density distribution given in the ove detailed description is to be inter- eted, and how useful it will be in com- ring the visual capacities of this and her fishes.

Müller ('52), in his exhaustive histo- ical study of the eye of the guppy, *bistes reticulatus*, found that cone den- y decreased as the eye enlarged although al number of cones in the retina in- eased, and that cones and other retinal ls are added by mitosis at the retinal argin as the retina enlarges. Lyall ('57a) ind that the spreading out of cones and e addition of new cells at the margin curred throughout growth in the trout *almo trutta*), but that the latter process creased in importance while the former curred at an almost constant rate. The mbination of the two processes in these ecies mean that cone density would de- ease with growth though not in propor- n to the increase in retinal surface.

To determine the relationship between cone density and eye size for the sardine, double cones per unit area were counted at the center of the ventro-temporal quarter and the center of the dorso-nasal quarter of the retinae of 22 specimens ranging from 53 mm to 220 mm in standard length. The pertinent data are given in table 2 and the double cones per unit area are plotted against lens diameter in figure 6. Values are included for the specimen already described (standard length 154 mm).

It is clear that cone density at both locations changes in inverse proportion to the increase in lens diameter, except that the two values for the smallest specimen are disproportionately high. Though these two values suggest some interesting questions in regard to the early phases of eye growth, they are eliminated from further consideration here for lack of additional small specimens to verify them. Lines fitted to the remaining points by the method of least squares are $y_{vt} = 461.8-50.7x$ and

TABLE 2

Sardinops caerulea

Mean density of double cones in the dorso-nasal quarter (n_{dn}) and the ventro-temporal quarter (n_{vt}) of 23 specimens arranged in order of standard length.

Standard length	Lens diameter	n_{dn}	n_{vt}
mm	*mm*		
53[1]	1.77	97	473
79	2.54	54	345
80	2.52	68	332
85	2.63	69	328
90	2.78	60	303
95	2.81	57	320
96	2.86	50	302
100	2.99	45	315
105	3.22	54	281
115[1]	3.26	53	312
125[1]	3.58	54	278
154	4.00	26	267
172[1]	4.49	44	256
175	4.59	35	249
180	4.88	32	243
199	5.20	31	172
200	5.00	36	215
210	5.49	26	201
211	5.31	—	164
214	5.56	30	192
216	5.81	26	165
219	5.76	27	165
220	5.73	29	148

[1] Formalin fixed specimens from old collections.

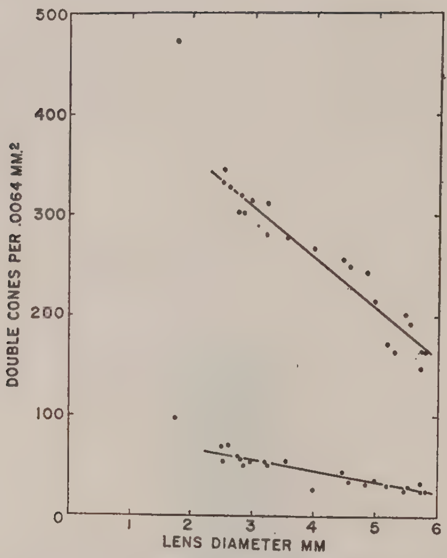


Fig. 6 *Sardinops caerulea.* Regression of the number of double cones per 0.0064 mm² on lens diameter in 23 specimens. The high series of points is from the center of the ventro-temporal quarter and the low series is from the center of the dorso-nasal quarter.

$y_{dn} = 87.6 - 10.5x$, where y_{vt} is the ventro-temporal double cone density, y_{dn} is the dorso-nasal double cone density and x is the lens diameter.

On the basis of the fitted lines the densities at these two locations decline at approximately the same rate, 11 or 12% per mm of lens diameter, over the size range observed. This indicates that cone density distribution remains relatively the same over the entire retina as the eye grows, at least during the adult stage, and that the pattern described earlier is characteristic of the species.

The densities themselves in any single specimen obviously cannot be taken as representative of the species. Density decreases 53% in the ventro-temporal quarter between lens diameters of 2.5 mm and 6.0 mm, and 60% in the dorso-nasal quarter over the same range. To be most meaningful, therefore, a description of cone density for a species should be based on several eyes of different size. Where comparisons between species are made on the basis of only one or a few specimens, speculation on the meaning of different densities should be qualified accordi

Nuclear layers. The thickness o various layers of the retina and the mated numbers of neurons in each a midpoints of the nasal and temporal are given in table 3.

The retina is thickest on the tem arc and this is due largely to a greater density of neurons in the nuclear layer at this location. The nuclear layer is conspicuously thin o temporal arc, compared to all other la In this part of the retina it consis nothing more than a double tier of nuclei. If rod nuclei are present are very scarce. In contrast to this nuclei on the nasal arc are abundant cone nuclei are relatively few and spaced.

The absence or virtual absence of on the temporal arc, hence in the *temporalis,* is consistent with the ge pattern of visual cell distribution a vertebrates. Where cones become h aggregated, rods tend to decrease in bers and are entirely eliminated fron *areae* of many species (Walls, '42). are never found in cone foveae.

The absence of rods in the *area* of *dinops* is also consistent with wh known of certain other clupeids. ('50), in describing the eye of the pean sardine, *Clupea pilchardus,* Baburina ('55), in describing the ey the common sprat, *Clupeonella deli* *lata caspia,* note that there are only seventh to one-ninth as many rods i "differentiated" as in the "undiffer ated" region. Baburina further rem that the sprat has more rods per li section in the "differentiated" region the sardine described by Vilter. Verh ('59) reports a similar condition, i.e. virtual absence of rods in the *area* o European herring, *Clupea palasii.*

Though the rods are not easily tinguished in routine preparations, reasonably certain from extensive ex nation that their outer segments are formly about 8 μ in length and somet less than 1 μ in diameter. The inner ments are composed of a small n which is probably the ellipsoid, a long mentous myoid and a round nucleu

TABLE 3

Sardinops caerulea

andard length 154 mm, lens diameter 4.00 mm. The thickness of the retinal layers in microns and estimated numbers of neurons under 0.0064 mm² in each at the midpoints of the nasal arc (N) temporal arc (T). Cone numbers are the mean counts from the middle segments of the dorso- l (N) and ventro-temporal (T) quarters. Nucleus diameters of neurons are given in microns.

Retinal layers							
	Thickness of layers			Number of cells		Nucleus diameter	
nal er	N	T	Cell types	N	T	N	T
L	53	55	Double cone	26	267	16.0	5.0
			Single cone	3	158	5.0	2.0
	43	19	Rod nuclei	2729	none	3.0	—
	22	22					
			Horizontal	31	195	6.0	4.0
	26	41	Bipolar	146	1689	4.4	4.0
			Amacrine	248	462	5.0	5.0
	24	53					
	7	7	Ganglion	25	89	6.0	6.0
	36	41					

ed in the outer nuclear layer of the na.

Except for the growth series all densities measurements given above were ob- ned from a specimen 154 mm in ndard length with a lens diameter of 0 mm.

Photomechanical changes

The light- and dark-adapted conditions illustrated for both the nasal and tem- al arcs in figures 35 to 38. In dark aptation the double cones on the nasal extend about 15 μ, and the smaller gle cones about 20 μ. The pigment cell ensions, which contract as the cones ve up, envelop the outer segments in h the light- and dark-adapted condi- ns. The rod myoids, during dark adapta- n, contract to varying degrees so that space around the cone myoids and psoids is entirely occupied by a strati- d mass of small rods.

On the temporal arc there is little if any vement of cones and pigment cell proc- es with changes in illumination. Myoids 7 to 10 μ long in the light-adapted as ll as in the dark-adapted condition ble 1), and thus appear to be stalks of ed length. They are the lower, more lightly shaded (basophilic) portions of the cones in figures 36 and 37.

Visual cells with myoids of fixed length are not uncommon among vertebrates that adapt to various light intensities by altering pupil size. In most teleosts and other vertebrates that do not have pupillary control of light entering the eye, there are retinal photomechanical changes that provide a protective pigment shield for the rods in bright light and provide the maximum possible space for them near the limitans in dim light. These changes are in general effected by the extension and contraction of the visual cell myoids and the pigment cell processes. Since rods are lacking in the *area* of the *Sardinops* retina, such changes would serve no useful purpose.

ALOSA SAPIDISSIMA

Extra-retinal features

Vertical lids and oculomotor muscles are as described for the sardine. The suspensory ligament originates slightly temporad of the vertical meridian, while the retractor muscle originates from the falciform process, which occupies the distal portion of the optic cleft, and inserts over the nasal surface of the lens.

The retina

Visual cell layer. The visual cell layer varies little in thickness except that it tapers rather abruptly near the margin of the retina. It contains double cones, single cones and rods, as well as extensions of the pigment epithelium cells. Both cones and rods vary considerably in density distribution over the retina, and the cones also vary in size.

Double cones are approximately four times as abundant in the ventro-temporal quarter as elsewhere in the retina (figs. 7, 27, 28). The zone of higher density is rather sharply defined by a crescentic cleft, exactly as in *Sardinops,* and may be considered an *area temporalis.* The highest density occurs in the ventral segment in the *area,* whereas it occurs in the central segment of the *area* in *Sardinops.* In both species, however, the difference between the segments in the *area* is small compared to the difference between them in the *area* and the rest of the retina.

Single cones are half as abundant as the doubles in the *area temporalis,* and the two together form the same kind of mosaic pattern that was found in *Sardinops.* In the extra-areal region, however, the double cones are arranged in fairly regular rows with single cones occurring irregularly. The ratio here varies from one single for every three to eight dou
Their distribution is not illustrated

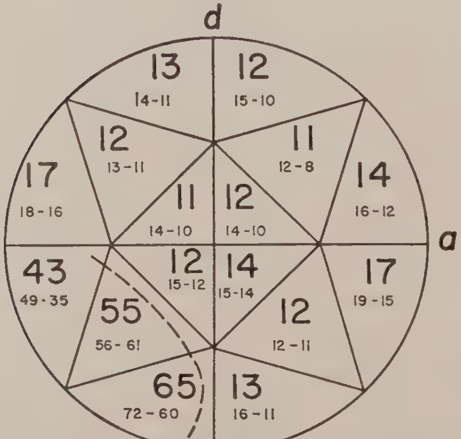


Fig. 7 *Alosa sapidissima.* The density of double cones in 16 segments of the retina.

Measurements of cones at the midp
of the nasal and temporal arcs are g
in table 4. These are assumed to be r
sentative of the extra-areal region an
area temporalis respectively. The si
cones are approximately two-thirds the
of the double cones at both locations.
kinds of cones are more slender on
temporal arc than on the nasal arc (
27, 28, 39, 40), but, in contrast to
situation in *Sardinops,* the double c
are not elongated. They are actually s
what shorter here than on the nasal
The single cones, however, are about
longer on the temporal than on the
arc.

Nuclear layers. The thickness of
ous nuclear layers and estimated num
of various retinal neurons are give
table 5. The inner nuclear layer and i
plexiform layer are considerably thi
on the temporal than on the nasal
but the outer nuclear layer and outer p
form layer, as well as the visual cell l
are slightly thinner on the temporal
The difference in the inner nuclear l
is obviously a reflection of the gr
number of neurons on the temporal

The thinner outer nuclear layer on
temporal arc is a reflection of fewer
nuclei in this part of the retina w
cones are more numerous. The nucl
the cones are also more numerous
course, but not numerous enough to
a double row in the outer nuclear lay

TABLE 4

Alosa sapidissima

Standard length 348 mm, lens diameter
mm. Cone measurements in microns at the
point of the nasal arc (N) and temporal arc
Inner segment measurements are based o
ellipsoid. Myoid length is zero on both a
the light-adapted condition.

	N		T
	Double cone	Single cone	Double cone
Outer segment length	32	24	32
Inner segment length	36	22	32
Inner segment diameter	24	9	14

TABLE 5

Alosa sapidissima

tandard length 348 mm, lens diameter 6.95 mm. The thickness of the retinal layers in microns and estimated numbers of neurons under 0.0064 mm² in each at the midpoints of the nasal arc (N) temporal arc (T). Cone numbers are the mean counts from the middle segments of the dorso-nasal and ventro-temporal (T) quarters. Nucleus diameters of neurons are given in microns.

nal er	Thickness of layers		Cell types	Number of cells		Nucleus diameter	
	N	T		N	T	N	T
L	125	102	Double cone	11	55	24	14
			Single cone	2	26	9	6
N	48	36	Rod nuclei	3255	2431	3.0	3.0
P	36	30					
			Horizontal	102	93	6.4	6.0
	42	70	Bipolar	242	1022	5.4	3.6
			Amacrine	63	195	8.8	5.6
	54	78					
	9	9	Ganglion	14	48	8.4	8.4
	72	32					

the sardines. They are all located at d project partly through the limitans th here and on the nasal arc.

The rods themselves are the same as ose in the sardine, i.e., the outer segents, which form a compact stratified ass around the cones, are composed of iter segments 5 to 8 μ in length and less an 1 μ in diameter, small nodular ellipids, and long filamentous myoids.

All densities and measurements given ove were obtained from a specimen 348 m in standard length with a lens diamer of 6.95 mm.

Photomechanical changes

The shad specimens were obtained by igling in the American River. It was ipractical to carry out the dark-adapting ocedure in the field, but it is obvious om the arrangement in the lightlapted retina that typical photomechanil changes must occur on both the nasal id temporal arcs. Rods are abundant on oth, and they are above the cones where ley are shielded from the light. To be inctional in dim light they must move own towards the limitans and away from le pigment cell processes as the cones iove up.

ENGRAULIS MORDAX

Extra-retinal features

The eye of the northern anchovy, *Engraulis mordax,* is completely covered by a tertiary spectacle as described by Walls ('42) for *Engraulis* sp. This transparent skin, which overlies but is not attached to the cornea, is no more than a fusion of ancestral lids. Walls records the function of the spectacle in the anchovy and the few other fishes that possess it as one of streamlining in swift swimming forms, but it is interesting to note that, for a great many of the snakes and lizards possessing such a structure, the function is given as one of protection of the eye from sand, bottom mud and other objects encountered while feeding. It is conceivable that the same may apply to fishes under some circumstances.

All the oculomotor muscles are moderately well developed except the *anterior rectus.* This muscle, which is inserted near the mesial center of the eye, is no more than a vestigial filament.

The heavily vascularized chorioid layer with its horseshoe-shaped chorioid gland forms the external covering of the retina and as such is the primary organ of nutrition. There is in addition a well developed network of hyaloid vessels spread across the inner face of the entire retina. This hyaloid circulation, which must augment the chorioid circulation considerably, indicates a relatively high retinal metabolism. There is no falciform process.

The lens in the anchovy is slightly subspherical, the lateral diameter being 3 to 4% less than the longitudinal diameter in all specimens measured. The suspensory ligament originates dorsally in the ciliary zone directly on the vertical meridian of the eye. The retractor muscle, though inserted along the ventro-nasal surface of the lens, originates in the ciliary zone ventrally and about 5° behind the vertical meridian. With this suspension the lens, upon contraction of the retractor muscle in accommodation, is rolled mesio-temporally probably almost in the horizontal plane.

The retina

Visual cell layer. The visual cell layer contains double cones and rods throughout as well as extensions of the pigment epithelium cells. Single cones are absent.

The density distribution of double cones in 16 segments of the retina shows a well defined *area temporalis* occupying most of the ventro-temporal quarter and extending somewhat into the dorso-temporal quarter. The optic cleft, which forms one boundary of the area, is straight and vertically aligned in contrast to the crescentic form in *Sardinops* and *Alosa.*

The means and ranges shown in figure 8 suggest that there is a maximum density somewhat above the center of the ventro-temporal quarter as shown in figure 9. The means and ranges also suggest that density in the extra-areal region is highest at the nasal margin and lowest at the dorsal and ventral margins. This tends to be the reverse of the distribution in the clupeids. A secondary maximum of this sort along the nasal margin has been described by Polyak ('57) for the trout, *Salvelinus fontinalis.* He suggests that the anterior and posterior *areae* in this species may be sections of a ring-shaped area that surrounds the larger central zone containing fewer cones. He found such ring-shaped zones in two other species; *Esox lucius* and *Labidesthes sicculus.*

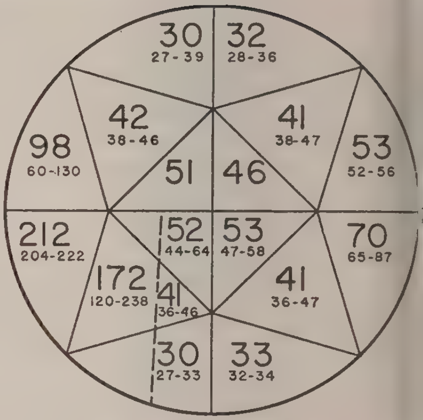


Fig. 8 *Engraulis mordax.* The densit double cones in 16 segments of the retina.

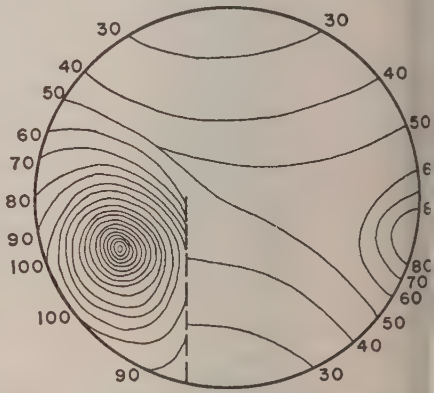


Fig. 9 *Engraulis mordax.* The probable ble cone topography of the retina.

is quite possible that the nasal and t poral *areae* in *Engraulis* are segments a peripheral zone of higher density, there is little doubt that the temporal a is the zone of greatest cone density in retina.

Because only double cones are pres there is no mosaic pattern. The cones arranged in precise parallel rows (25, 26) with their long diameters en end and almost parallel. Each row cones is encased in the extensions of overlying row of pigment epithelium c The small rods form massed rows alternate with them.

easurements of cones at the midpoints
ne nasal and temporal arcs are given in
e 6. The cones are longer and much
e slender on the temporal arc where
sity is greater than on the nasal arc
s. 25, 26, 41–48). Most of the length
erence is in the outer segments, which
tain the photosensitive pigment. Cone
is fairly uniform along the nasal arc,
along the temporal arc length de-
ises markedly from the center towards
cleft and the temporal margin. This
further indication that the maximum
in the center of the *area* rather than
r the temporal margin.

uclear layers. All layers of the retina
thicker on the temporal arc than on
nasal arc (table 7) reflecting the
ater abundance of neurons as well as
toreceptors temporally.

lthough the outer nuclear layer dif-
little in thickness on the two arcs,
nuclei are considerably less abundant
porally. Cone nuclei, because of their
ater abundance temporally, occupy a
ch larger proportion of the volume here
n nasally. In this species, incidentally,
e nuclei on the nasal arc are located in
center of the outer nuclear layer rather
n at the limitans as in *Sardinops*.

he rods themselves are small and uni-
m in size. As in the clupeids they are
nposed of an outer segment 5 to 8 μ long and a little less than 1 μ in diameter, small nodular ellipsoids, and filamentous myoids of varying lengths.

TABLE 6

Engraulis mordax

Standard length 131 mm, lens diameter 2.92 mm. Cone measurements in microns at the midpoints of the nasal arc (N) and temporal arc (T). Inner segment measurements are based on the ellipsoid. Myoid length is zero in the light-adapted retina.

	N	T
	Double cone	Double cone
Outer segment length	12	21
Inner segment length	21	23
Inner segment diameter	10	4

All densities and measurements given above were obtained from a specimen 131 mm in standard length with a lens diameter of 2.92 mm (2.85 laterally and 2.98 longitudinally).

Photomechanical changes

Adaptation to different levels of light intensity is achieved by photomechanical changes in the visual cell layer of the retina. In general among teleosts the cones are contracted to the limitans in bright light, and the rods are extended away from it and shielded from the light by intervening fuscin. In dim light the

TABLE 7

Engraulis mordax

tandard length 131 mm, lens diameter 2.92 mm. The thickness of the retinal layers in microns and
estimated numbers of neurons under 0.0064 mm² in each at the midpoints of the nasal arc (N)
temporal arc (T). Cone numbers are the mean counts from the middle segments of the dorso-
al (N) and ventro-temporal (T) quarters. Nucleus diameters of neurons are given in microns.

	Retinal layers						
nal ver	Thickness of layers		Cell types	Number of cells		Nucleus diameter	
	N	T		N	T	N	T
CL	60	82	Double cone Single cone	41 none	172	10 —	4 —
N	26	29	Rod nuclei	3923	2109	2.6	2.6
P	14	19					
	14	17	Horizontal Bipolar Amacrine	30 383 145	112 1000 288	7.0 3.0 5.6	6.0 3.4 5.2
	7	7	Ganglion	32	103	6.6	5.8
	24	29					

cones extend away from the limitans and the rods contract to it, forming a solid palisade exposed to the light that enters the eye. This species differs from the two clupeids in that the extensions of the pigment cells are packed with guanin and do not expand and contract. The fuscin granules migrate through the guanin. When the fuscin migrates out of the extensions into the bodies of the pigment cells in dark adaptation, the guanin becomes a reflecting layer for the rods. This constitutes an occlusible retinal tapetum, which is present over the entire retina. Similar tapeta described by Wunder ('30) for certain freshwater fishes are restricted to certain parts of the retina.

Photomechanical changes in the anchovy were studied with some care to demonstrate the existence of the tapetal mechanism. Walls ('42) notes that guanin may be present in the retinae of the *Mormyridae, Elopiidae* and *Thunnidae*, some anchovies, some mackerels, the louvar and one serranid (*Polyprion*), but he refrains from classifying these as having effective tapeta because they all also have fuscin and are not known to exhibit pronounced photomechanical changes. Doubts about photomechanical changes were apparently based on lack of expansion and contraction of pigment cell extensions, although Parker ('32), in his excellent summary of retinal pigment migrations, points out that in occlusible retinal tapeta the pigment cell extensions are fixed except that there might be slight expansion and contraction at the tips.

The extent and rate of photomechanical changes were determined by examining cross sections of the retinae of nine specimens removed from an open bait tank during the course of one evening. Figure 10 illustrates four stages of the process. Figures 41 to 48 are photographs of the visual cell layer in both the light-adapted and dark-adapted condition.

Along the nasal arc of the light-adapted eye the extensions of the pigment cells almost touch the limitans. The pigment cells are packed with guanin but have heavy concentrations of fuscin in their tips. Fuscin is also diffused through the guanin imparting a dull yellowish color to these cells in histological preparations.

During dark adaptation most of
fuscin migrates into the pigment
bodies prior to the movements of the vi
cells and the guanin mass then becom
brilliant white. The small amoun
fuscin that remains in the tips does
interfere with the reflecting functio
the guanin mass. The contracted
myoids occupy approximately the lev
this fuscin, while the palisade of pl
labile outer segments is virtually
mersed in the guanin above.

Along the temporal arc the arrange
is somewhat different. First, the tips o
pigment cell processes do not exten
the limitans. Second, there is no fixed
centration of fuscin in the tips. All
fuscin migrates into the pigment
bodies somewhat in advance of the vi
cell movements. The guanin itself t
to concentrate in the reverse directio
ward the tips.

The space between the tips of the e
sions and the limitans is probably n
sary on the temporal arc to accommo
the increased mass of thickened
myoids in the dark-adapted condition.
cause the pigment cell extensions ar
slender and close packed here, suffi
space could not be gained merely by
eral displacement of them as on the r
arc. The location of the tips above
limitans puts them on a level with
outer segments of the rods during
dark-adapted condition, and any fusci
maining at this level would interfere
the effectiveness of guanin reflection

ANCHOA COMPRESSA

Extra-retinal features

As in the northern anchovy the e
covered by a tertiary spectacle, the
terior rectus muscle is vestigial, and
inner surface of the retina is covere
a network of hyaloid vessels. Also,
suspensory ligament originates dorsall
the vertical meridian, and the retr
mucle originates ventrally, slightly be
the vertical meridian.

The retina

Visual cell layer. The visual cell
contains double cones and small ro

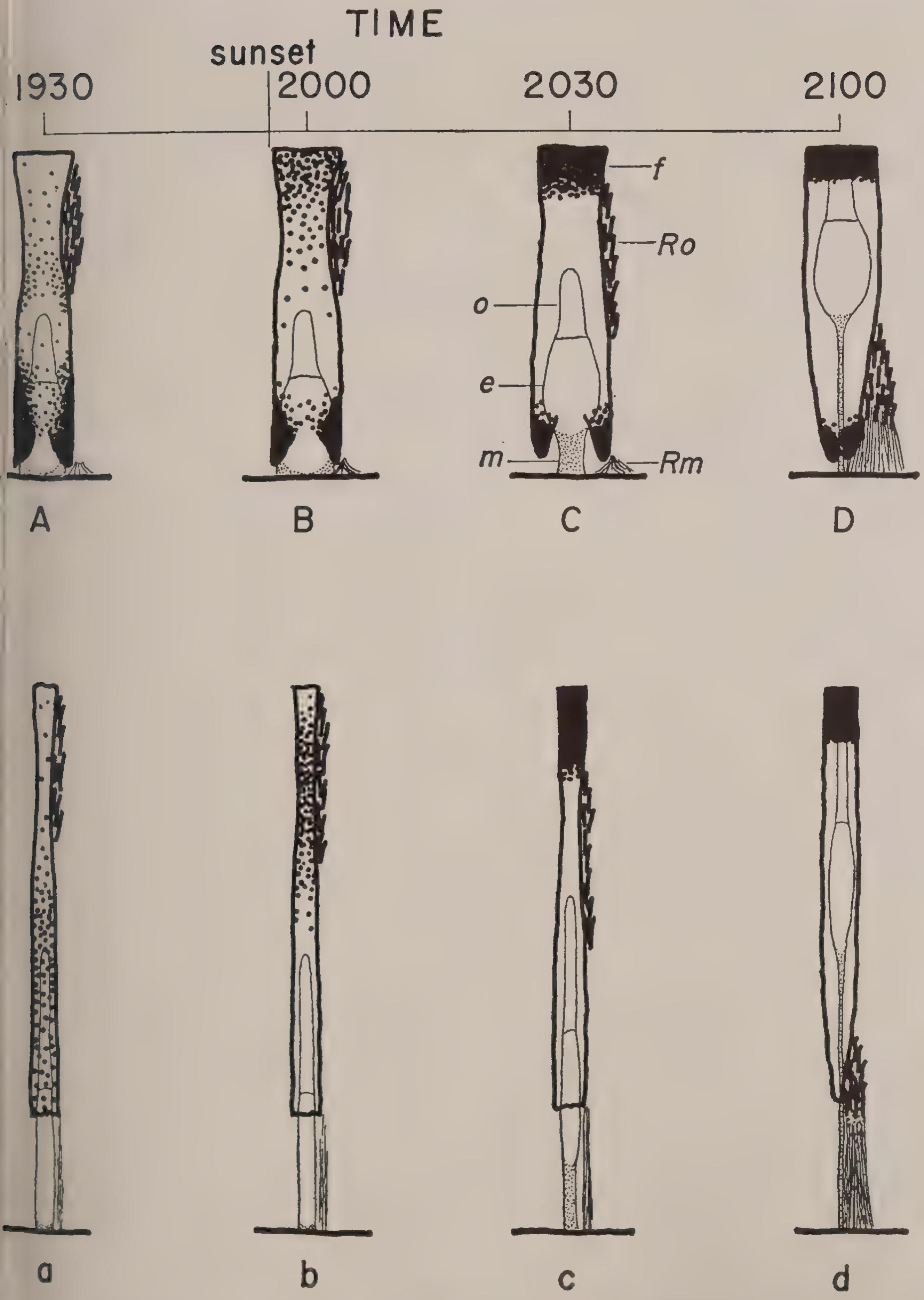

TIME
sunset
1930
2000
2030
2100
f
Ro
o
e
m
Rm
A
B
C
D
a
b
c
d

Fig. 10 *Engraulis mordax.* Four stages in the process of dark adaptation. The pigment cells filled with guanin through which the fuscin moves. A, B, C, and D, nasal arc; a, b, c, and d, nporal arc.

well as extensions of the pigment epithelium cells. Single cones are absent.

Cone density is about twice as high in the ventro-temporal quarter as in the rest of the retina (figs. 11, 29, 30). Though the difference is not great, the change is rather abrupt along the optic cleft, and the portion of the ventro-temporal quarter behind the cleft may be considered an *area temporalis* that extends broadly into the dorso-temporal quarter. As in *Engraulis*, the maximum cone density is above the center of the ventro-temporal quarter, almost on a level with the horizontal meridian.

In the extra-areal region cone density is slightly lower along the ventral margin and slightly higher along the nasal margin than elsewhere. This resembles the distribution in *Engraulis*, but the gradients are not nearly as distinct.

Because single cones are absent, there is no mosaic arrangement. Double cones, encased in extensions of overlying pigment epithelium cells, are arranged in parallel rows with the rods massed in rows between them.

Cone dimensions (table 8) are much more alike on the two arcs than in *Engraulis*. The temporal cones are just a little longer and thinner than the nasal cones. The diameters, furthermore, are intermediate between the extremes in *Engraulis*, i.e., the nasal cones are not as plump and the temporal cones are not as slender. However, the cones are a
longer than those of *Engraulis* on
arcs.

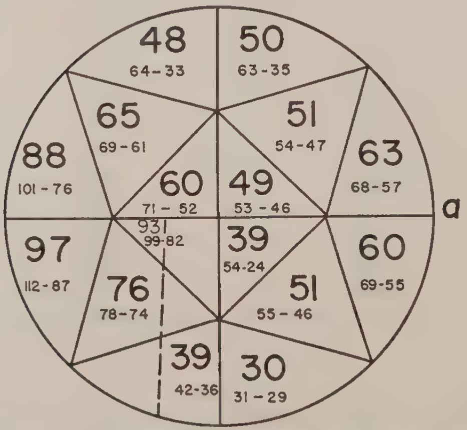


Fig. 11 *Anchoa compressa.* The density of double cones in 16 segments of the retina.

TABLE 8

Anchoa compressa

Standard length 103 mm, lens diameter
mm. Cone measurements in microns at the
point of the nasal arc (N) and temporal arc
Inner segment measurements are based o
ellipsoid. Myoid length is zero on both arcs i
light-adapted condition.

	N
	Double cone
Outer segment length	16
Inner segment length	23
Inner segment diameter	8

Nuclear layers. The nuclear la
tend to be a little thicker, and the neu
of the inner nuclear and ganglion la
are one and a half to two times as a
dant on the temporal arc as on the n
arc (table 9). These differences are
mensurate with the difference in
densities.

The density of rod nuclei is about
same on the nasal arc as in *Engraulis*,
on the temporal arc it is about
greater than in *Engraulis*. This is con
ent with the differences in cone der
distributions of the two species in that
lower density of cones temporally
Anchoa leaves more space in the visual
layer for rods.

As in the three species so far descri
rods are very small and uniform in
throughout the retina. They are comp
of outer segments 5 to 8 μ in length
less than 1 μ in diameter, small nod
ellipsoids, and long filamentous my
All densities and measurements g
above were obtained from a specimen
mm in standard length with a lens di
eter of 3.35 mm.

Photomechanical changes

Though no dark-adapted specin
were examined, the organization of
ment epithelium and photoreceptor
exactly like that of *Engraulis*, so it is
sonable to assume that photomechar
changes are the same. The pigment c
which contain both fuscin and gua
have extensions that almost reach

TABLE 9

Anchoa compressa

ndard length 103 mm, lens diameter 3.35 mm. The thickness of the retinal layers in microns and timated numbers of neurons under 0.0064 mm² in each at the midpoint of the nasal arc (N) mporal arc (T). Cone numbers are the mean counts from the middle segments of the dorso- (N) and ventro-temporal (T) quarters. Nucleus diameters of neurons are given in microns.

Retinal layers						
Thickness of layers		Cell types	Number of cells		Nucleus diameter	
N	T		N	T	N	T
72	114	Double cone Single cone	51 none	76 —	8 —	6 —
30	42	Rod nuclei	4038	3225	3.0	3.0
12	12					
		Horizontal	44	74	6.0	4.8
14	18	Bipolar	317	696	3.6	3.2
		Amacrine	182	230	4.4	5.4
26	22					
6	6	Ganglion	62	145	4.6	4.4
48	36					

tans on the nasal arc, but only cover cone outer segments on the temporal (figs. 49, 50). Fuscin is dense at the of the extensions and some of it probremains there in the dark-adapted lition.

comparison of figures 41 to 50 sugs that there is more fuscin in the pigit cells of *Anchoa* than in those of *raulis*. Whether the differnce is real pparent and what significance it may e is not known. The fact that the pigit epithelium cells contain abundant nin indicates that the species has an usible retinal tapetum.

TRACHURUS SYMMETRICUS

Extra-retinal features

ertical lids are present but well sepad. The nasal lid covers one-third of cornea, and the temporal lid perhaps uarter of it.

he six oculomotor muscles are well eloped, all having typical peripheral ertions except the *anterior rectus*. This scle has two components: a lower ad, thick segment inserted slightly ad of the center, and an upper, slender ment which expands to a broad insern over the nasal surface of the eyeball.

The chorioid layer, which includes a horseshoe-shaped chorioid gland, is a well developed plexus. A low falciform process, running the length of the optic cleft, functions as a secondary organ of ocular circulation. It is entirely unpigmented and contains a sparse capillary network.

The spherical lens is suspended by a ligament that originates in the ciliary zone dorsally and slightly behind the vertical meridian. The well developed retractor muscle, which originates at the foot of the falciform process just in front of the vertical meridian, terminates bluntly but has a long, transparent, ligamentous extension that inserts over the ventro-anterior surface of the lens.

The retina

Visual cell layer. The visual cell layer contains double cones, single cones and small rods as well as the extensions of the pigment epithelium cells.

Double cone densities (fig. 12) are lowest in the dorso-nasal quarter and highest in the ventro-temporal quarter. The most likely interpretation (fig. 13) is that cone density increases from a low point in the dorso-nasal quarter towards the margin in all directions, becoming twice as great

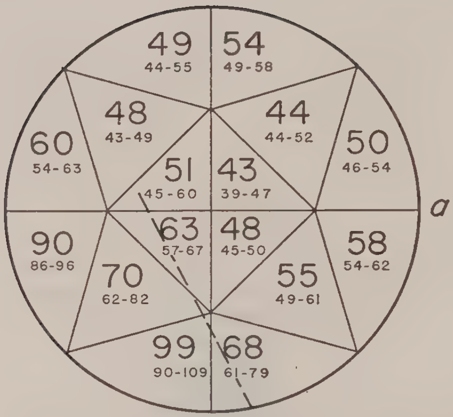


Fig. 12 *Trachurus symmetricus.* The density of double cones in 16 segments of the retina.

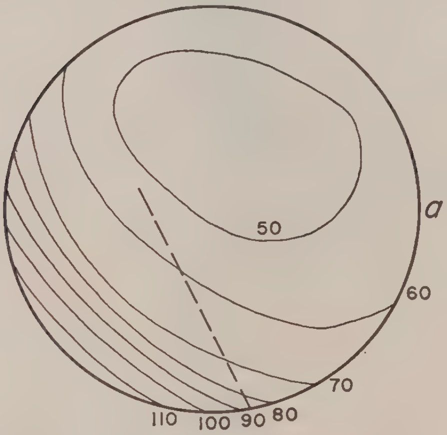


Fig. 13 *Trachurus symmetricus.* The probable double cone topography of the retina.

along the ventral and temporal margin as elsewhere. Because the cone gradient is so broad, and because there does not seem to be a point or plateau of maximum cone density, no part of the retina can readily be designated an *area temporalis,* nor is the optic cleft a line of demarcation between two zones of different cone density.

Single cones are exactly half as abundant as the double cones throughout the retina. The two kinds of cones are arranged in a box-like mosaic pattern (figs. 31, 32) similar to those described for the *areae temporales* in *Sardinops* and *Alosa.* The space between the cones is occupied by rods and the extensions of the pig
epithelium cells.

Measurements of cones (table 1
the midpoints of the nasal and tem
arcs indicate that single cones are h
three-quarters the size of double
throughout the retina. The double
themselves decrease somewhat in size
porally. The single cones, however
very much the same on both the nasa
temporal arcs, except that they are
sistently a little more slender tempo
It should be noted that inner seg
length is the length of the ellipsoid
that the nucleus, which is entirely a
the limitans, occupies a space of se
microns between the inner end of
ellipsoid and the limitans (figs. 51,

Nuclear layers. The several nu
layers differ very little in thickness o
nasal and temporal arcs (table 11)
the neurons in the inner nuclear and
glion layers tend to be one and a
times as abundant temporally. Th
polars, which are by far the most nu
ous class, have characteristically sm
nuclei on the temporal arc. This prob
accounts for the lack of relationshi
tween inner nuclear layer thickness
cell numbers on the two arcs.

The outer nuclear layer is a little
ner temporally than nasally, and in
species the difference is probably a
tion of the density of rod nuclei, w
are only three-quarters as abundant
porally as nasally. Cone nuclei are la
above the limitans and hence contr

TABLE 10

Trachurus symmetricus

Standard length 208 mm, lens diamete
mm. Cone measurements in microns at the
point of the nasal arc (N) and temporal arc
Inner segment measurements are based o
ellipsoid. Myoid length is zero in the light-ad
condition.

	N		T	
	Double cone	Single cone	Double cone	S
Outer segment	16	10	14	
Inner segment length	22	13	20	
Inner segment diameter	12	5	8	

TABLE 11

Trachurus symmetricus

ndard length 208 mm, lens diameter 6.20 mm. The thickness of the retinal layers in microns and stimated numbers of neurons under 0.0064 mm^2 in each at the midpoint of the nasal arc (N) emporal arc (T). Cone numbers are the mean counts from the middle segments of the dorso- (N) and ventro-temporal (T) quarters. Nucleus diameters of neurons are given in microns.

Retinal layers						
Thickness of layers		Cell types	Number of cells		Nucleus diameter	
N	T		N	T	N	T
90	103	Double cone	44	70	12	8
		Single cone	22	35	5	5
41	36	Rod nuclei	3939	3004	2.4	2.6
24	19					
36	38	Horizontal	42	107	5.6	5.0
		Bipolar	736	1355	3.4	3.0
		Amacrine	169	284	5.4	5.6
36	48					
12	12	Ganglion	49	66	6.4	5.6
84	48					

to the volume of the inner nuclear r.

he rods are similar in size to those in other species. They are composed of er segments less than 10 μ in length less than 1 μ in diameter, small nod- ellipsoids, and long filamentous oids. The outer segments are uniform size throughout the retina.

ll densities and measurements given ve were obtained from a specimen mm in standard length with a lens meter of 6.20 mm.

Photomechanical changes

hotomechanical changes involve move- nts of visual cells and extensions of ment epithelium cells over the entire na. In the light-adapted condition the cin-filled extensions of the pigment thelium cells, which envelop the cone er segments, effectively shield the ex- ded rods from light entering the eye. dark adaptation the cones and attend- pigment cell extensions move away m the limitans as the rods move down form a stratified layer exposed to the nt. Only the light-adapted retina is strated (figs. 51, 52).

PNEUMATOPHORUS DIEGO

Extra-retinal features

Vertical lids are present, but well separated. They are continuous above, but the anterior lid overlaps the posterior lid broadly below. A second fold of transparent skin occurs nasally.

The six oculomotor muscles are broad and rather flat. All are inserted peripherally except the *anterior rectus*. As in *Trachurus* this muscle has two components, the ventral one inserted centrally, the dorsal one broadening to a peripheral insertion over the dorso-nasal surface of the eye-ball.

The well developed chorioid layer, with its horseshoe-shaped chorioid gland, is the primary organ of circulation. The secondary organ of circulation is a simple falciform process running the length of the optic cleft. Except for the sparse capillaries, which are pigmented, the falciform process is transparent almost to the margin of the retina. It extends as a broad and heavily pigmented ribbon over the retractor lentis, which is flattened against the ciliary zone, to an insertion along the margin of the pupil.

The suspensory ligament originates dorsally and slightly behind the vertical meridian of the eye. The retractor lentis is a thick but flat muscle originating in and, as already stated, lying flat against the ciliary zone. It terminates bluntly below the margin of the pupil, but a transparent ligament extends from it to insert over the ventro-nasal surface of the lens.

The retina

Visual cell layer. The visual cell layer contains double cones, single cones and small rods as well as the extensions of the pigment epithelium cells.

Double cone counts in the 16 segments are given in figure 14, and the most likely topographical interpretation of these counts is shown in figure 15. Double cone density appears to be almost homocentric. The lowest occur a little nasad of the center, and density increases from here toward the margin in all directions. There is very little difference in density along the nasal and temporal margins, both of which, however, show a greater density than the dorsal and ventral portions of the margin.

The optic cleft, which runs in a straight line from a point on the ventral margin slightly in front of the vertical meridian to a point well behind the center of the retina, is not a line of demarcation between two zones of different cone density. In view of this and the nature of the cone distribution, no part of the retina ca designated an *area temporalis* on the of double cone distribution.

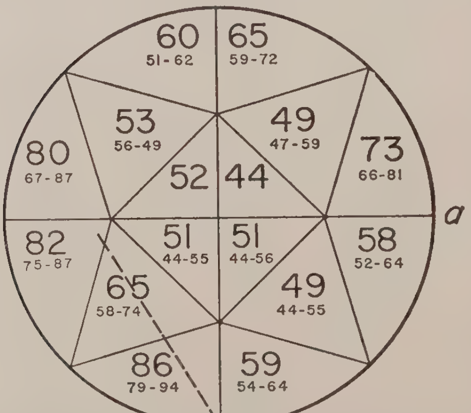


Fig. 14 *Pneumatophorus diego.* The density of double cones in 16 segments of the retina.

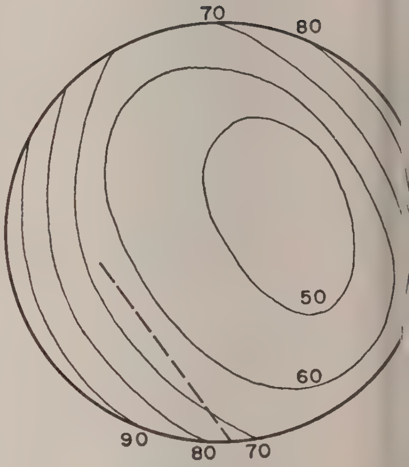
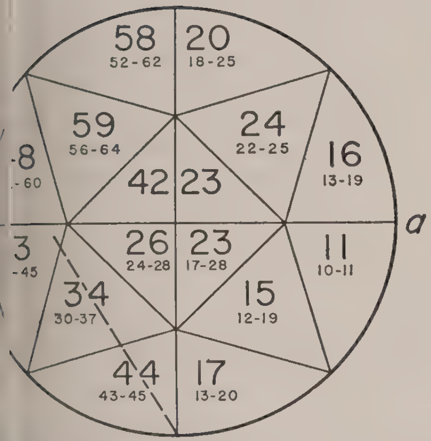


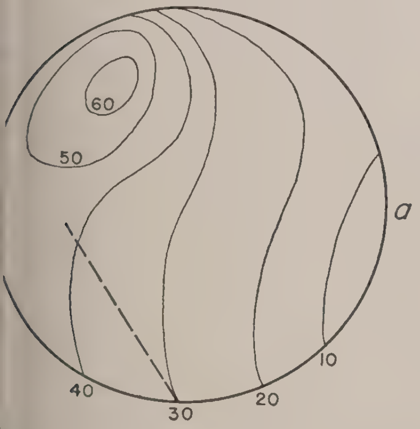
Fig. 15 *Pneumatophorus diego.* The pr double cone topography of the retina.

The distribution of single cones 16, 17) is quite different than that o double cones. Density is lowest alon nasal margin and increases sixfold maximum in the dorso-temporal qu The differential distribution of doubl single cones means, of course, tha mosaic arrangement of these ele varies over the retina. For the most they form a box pattern in which the is two doubles to one single, but na the ratio is as high as five doubles t single, and dorso-temporally it is o one. In the latter region the double single cones occur in alternate rows 34). Toward the nasal margin the ble cones retain the box pattern, but gle cones are frequently not present i center of these boxes.

Though there is no well defined *temporalis*, the dorso-temporal quart undoubtedly the region of highest v acuity. The density of single con clearly greater here than elsewhere, when both kinds of cones are adde gether and averaged by quarters th sult is dorso-temporal 114, ventro-tem 108, dorso-nasal 78, and ventro-nas cones per unit area. Thus the tem half of the retina has a cone density a



g. 16 *Pneumatophorus diego.* The density ngle cones in 16 segments of the retina.



g. 17 *Pneumatophorus diego.* The probable le cone topography of the retina.

greater than the nasal half, and the so-temporal quarter has a density about greater than the ventro-temporal rter.

one measurements (table 12) at the points of the nasal and temporal arcs cate that double cones vary little in over the whole retina and that single es are considerably larger temporally n nasally. Single cones are, in fact, est in the dorso-temporal quarter (figs. 54) where their density is greatest. double cones also tend to be slightly er dorso-temporally.

During the courrse of this study two live specimens of rather different standard length than the one described above were examined. The retinae of these specimens were sectioned tangentially approximately at the midpoints of the ventro-temporal and dorso-nasal quarters to gain some impression of the relation between cone density and eye size for the species. The numbers of double cones per unit area are plotted against lens diameter in figure 18. Mean densities from the center segments of the ventro-temporal and dorso-nasal

TABLE 12

Pneumatophorus diego

Standard length 228 mm, lens diameter 6.00 mm. Cone measurements in microns at the midpoint of the nasal arc (N) and temporal arc (T). Inner segment measurements are based on the ellipsoid. Myoid length is zero in the light-adapted condition.

	N		T	
	Double cone	Single cone	Double cone	Single cone
Outer segment length	18	10	21	14
Inner segment length	19	12	22	17
Inner segment diameter	11	5	12	8

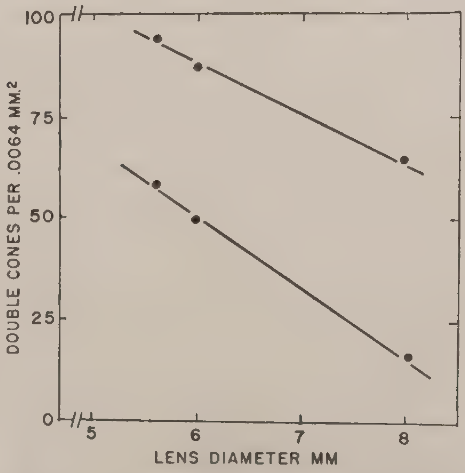


Fig. 18 *Pneumatophorus diego.* The number of double cones per 0.0064 mm² on lens diameter for three specimens. The high points are from the ventro-temporal quarter and the low points from the dorso-nasal quarter.

quarters of the specimen already described are included. Single cone densities are not given because the ratio was two doubles to one single in all three specimens at these locations.

Although three specimens are not enough to establish a reliable estimate of the relationship between density and eye size, it is clear that densities do decline substantially as the eye grows. The ventro-temporal density for the specimen with the 6.00 mm lens is considerably out of line with the other two, but re-examination of figure 14 offers a possible explanation. Mean values for the two marginal segments in the ventro-temporal quarter are in the eighties, so it is possible that a more representative value for the center segment would also be in the eighties. It must be remembered that these segments were sectioned only at one small point approximately in the center, and also that nothing at all was known about density distributions when the sectioning was being done. It is quite probable that the center segment was sectioned at a point further from the margin than the other two and therefore at a lower density in the gradient.

Whether or not the pattern of density over the retina remains relatively the same during growth cannot be determine this data. If the rate of decline same at all locations, as was the cas *Sardinops*, the relative distribution remain essentially the same with g

Nuclear layers. All the nuclear tend to be slightly thicker on the ten arc than on the nasal arc (table 13) the neurons of the inner nuclear an glion layers are one and a half to two as abundant temporally as nasally. bipolars, which are the most abu class of neurons, have nuclei of ide form and size on both arcs in *Pneu phorus*, whereas they differ in si *Trachurus*.

Rod nuclei in the outer nuclear lay only about four-fifths as abundant te ally as nasally. This layer is, neverth somewhat thicker temporally, perha cause the cone nuclei, which are abundant temporally, are located i outer nuclear layer where they woul tribute to the volume of the layer.

The rods themselves are similar i to those in the other species desc They are composed of outer segment than 10 μ in length and less than 1 diameter, small nodular ellipsoids, long filamentous myoids. The oute

TABLE 13

Pneumatophorus diego

Standard length 228 mm, lens diameter 6.00 mm. The thickness of the retinal layers in micro the estimated numbers of neurons under 0.0064 mm^2 in each at the midpoint of the nasal ar and temporal arc (T). Cone numbers are the mean counts from the middle segments of the nasal (N) and ventro-temporal (T) quarters. Nucleus diameters of neurons are given in mi

Retinal layer	Thickness of layers		Cell types	Number of cells		Nucleus di
	N	T		N	T	N
VCL	65	108	Double cone Single cone	49 24	65 34	12 5
ON	46	53	Rod nuclei	4602	3843	2.0
OP	27	38				
IN	30	36	Horizontal Bipolar Amarcine	44 735 192	103 1575 367	6.0 2.4 5.4
IP	43	65				
G	10	10	Ganglion	31	48	6.6
F	58	38				

s are uniform in size throughout the a.

cept for the two additional specimens in the description of eye growth, all ities and measurements given above obtained from a specimen 228 mm andard length with a lens diameter of mm.

Photomechanical changes

s in *Trachurus*, photomechanical ges occur over the whole retina. The in-filled extensions of the pigment epi- ium cells, which envelop the cone outer nents, shield the rods from light enter- the eye in the light-adapted condition. lark adaptation the cones and attend- pigment cell extensions move away n the limitans as the rods move down orm a stratified layer exposed to the t. Only the light-adapted retina is strated (figs. 53, 54).

DISCUSSION AND CONCLUSIONS

rom the preceding descriptions it is r that all six species have what Walls s arhythmic or 24-hour eyes: each is ipped with a good rod system for dim t vision and a good cone system for ht light vision, and of course the proc- of photomechanical change is well eloped. The cones are large structures ile the rods are very small and numer- . The functional significance of very all rods is not known, but the nature the photomechanical changes suggests t it may be a matter of fluidity. When rhodopsin mass is functional in the k-adapted condition it forms a carpet se to the limitans. In the light-adapted dition it must be shielded, and this is complished by movement upward into spaces between the extensions of pig- nt epithelium cells surrounding the es. Small rods would facilitate re- gnment from a shallow stratified layer ainst the limitans to long, narrow, ver- al clusters or rows between the pigment l extensions.

The anatomical features that illustrate differences in the eyes of the six ecies described in this report are sum- arized in table 14. The maximum stand- d lengths given in the first row are ap- oximations based on information from the authors cited. The maximum lens diameters are approximations obtained by extrapolations of the lens diameter-standard length information obtained during this study. The error associated with these figures is unknown, but they are at least accurate enough to illustrate gross differences between the species.

It is obvious from the table that the two engraulids differ markedly from the other four species in that they have occlusible retinal tapeta and do not have single cones. This combination suggests that the two engraulids are better equipped than the others for vision in dim light and not as well equipped as they for vision in bright light.

There are several structural kinds of tapeta among the vertebrates, but they all perform the same function. Tapeta lower the visual threshold and improve the efficiency of vision in dim light by delivering a greater proportion of the photons emanating from an object to the rhodopsin screen formed by the rods than would reach it otherwise. Pirenne ('56) explains that the tapetum accomplishes this by reflecting back through the rods some portion of the photons that initially passed through them without being absorbed by rhodopsin molecules. He calculates that the tapetum in the cat should improve its sensitivity by a factor of at least 1.4, and it is reasonable to suppose that sensitivity in the engraulids is improved to some such degree by the presence of a reflecting structure.

As mentioned above, the engraulids, in addition to having tapeta, are lacking in single cones. The functional differences between single and double cones are not yet understood, but Lyall ('57b) points out that relative distribution of the two types in teleosts suggests that double cones are associated with vision in deep water. She found that singles occurred in lower ratio to doubles in deep water salmonids than in forms living in shallower water, and that the cod (*Gadus morhua*) and the whiting (*G. merlangus*), which live at considerable depths, have double cones almost exclusively. She suggests that the association of double cones with vision in deep water may be due to greater sensitivity of the doubles so that they are inter-

TABLE 14

Summary of eye characteristics of the six species described in this report. The maximum sta lengths and lens diameters are only approximations

	Sardinops caerulea	*Alosa sapidissima*	*Engraulis mordax*	*Anchoa compressa*	*Trachurus symmetricus*	*Pneumat phorus diego*
Maximum standard length[1] (mm)	285	560	185	160	700	600
Maximum lens diameter (mm)	7.0	12.0	4.0	4.0	14.0	14.0
Specimen standard length (mm)	154	348	131	103	208	228
Specimen lens diameter (mm)	4.00	6.95	2.92	3.35	6.20	6.0
Double cones per 0.0064 mm²						
Nasal	26	11	41	51	44	49
Temporal	267	65	212	97	99	86
Location in VT quarter	center	lower	upper	upper	lower	lower
Single cones per 0.0064 mm²						
Nasal	3	2	0	0	22	24
Temporal	158	26	0	0	48	34
Rods per 0.0064 mm²						
Nasal	2729	3255	3923	4038	3939	4602
Temporal	0	2431	2109	3225	3004	3743
Bipolars per 0.0064 mm²						
Nasal	146	242	383	317	736	735
Temporal	1689	1022	1000	696	1355	1575
Pigment epithelium cells						
Characteristic	contractile	contractile	tapetum	tapetum	contractile	contracti
Pigment type	fuscin	fuscin	fuscin and guanin	fuscin and guanin	fuscin	fuscin
Anterior rectus muscle						
Insertion	mesial	mesial	mesial	mesial	mesial and nasal	mesial and nasal
Thickness	medium	medium	thin	thin	thick	thick

[1] *S. caerulea*, Mosher, '54; *A. sapidissima*, La Pointe, '57; *E. mordax*, Miller, '55; *A. compressa*, Roede *T. symmetricus*, Roedel, '53; *P. diego*, Fitch, '55.

mediate between single cones and rods, or to differences in spectral sensitivities, since different wavelengths of light penetrate to different depths. Svaetichin and MacNichol ('58) have shown certain fishes known to live at depths of 30 to 70 meters to have photopic responses with spectral absorption maxima at somewhat lower wavelengths than fishes known to live close to the surface in shallow water. The surface fishes exhibited, in addition, characteristic responses to light of different wavelengths. These chromaticity responses are thought to be combinations of responses of receptor cells having different spectral sensitivities. The authors are careful to point out, however, that since the sponses were picked up from the nu and plexiform layers of the retina, the not furnish direct evidence of the na of the photoreceptors themselves.

Tamura ('57) also found single c to be more abundant in species reput live close to the surface. Of the sp examined by Tamura, *Scomber japon* which is known to spend much of its at the surface, has single and double c in equal density. Several others know live moderately close to the surface, half as many singles as doubles, and species that were caught at depths tween 100 and 300 meters have only

One of the latter, furthermore, has
ble cones only in the temporal region,
remainder of the retina consisting en-
y of rods.

he absence of single cones, therefore,
onsistent with the presence of a tape-
because both facts seem to imply
ptation to an environment of subdued
mination. The adaptive significance of
combination, described for the en-
lids, is reenforced by the occurrence
he same combination in the fishes that
mura ('57) examined: the five species
h tapetal structures are precisely the
s that do not have single cones. They
er from the two engraulids described
e in that their tapeta are located in the
rioid layer overlying the retina and are
refore not occlusible. Since all of them
species that live constantly at inter-
diate or great depths where the light is
ays dim, they have no need for occlusi-
tapeta. *Engraulis* and *Anchoa*, on the
er hand, are known to spend much of
ir time close to the surface in daylight
though dim light situations may have
at importance in their ecology, it is
ential that their rods be shielded and
reflecting property of the guanin elimi-
ed by the wide dispersion of fuscin
nules when they are in bright light.

One possible functional advantage of
lusible tapeta is suggested by Wunder's
0) description of eight percids and
rinids living in the shallow and fre-
ently turbid waters of Lake Balaton,
ngary. In addition to these, occlusible
eta have been described for only three
four other teleosts, all of them inhabit-
ts of fresh water. The tapeta of the
ke Balaton fishes differ from those in
e two engraulids described in this report
being restricted to certain parts of the
ina, whereas those of the engraulids
cur over the entire retina. The advan-
ge of more efficient dim light vision in
avily silted water needs no comment,
t Wunder ('30) observes that the func-
nal interpretation is apparently not so
nple because some of the Lake Balaton
ecies also occur in less turbid habitats
here the possible advantages of a tape-
m are not nearly so obvious.

The same paradox exists over func-
nal advantage in the case of *Engraulis* and *Anchoa*. *Engraulis*, as mentioned above, is commonly found near the surface both night and day. Field observations of CalCOFI biologists over the years indicate, however, that the species is often associated with "green" (turbid) water, at least during daylight.

There is, of course, a very good possibility that the tapetum is characteristic of the family Engraulidae. This would add another dimension to the paradox, because different engraulids are adapted to quite different environmental niches. Peterson ('56), for example ,shows that many engraulids in the Gulf of Nicoya feed predominantly on small zooplankters, though at least one (*Lycengraulis poeyi*) devours small fish voraciously, while another (*Cetengraulis mysticus*) subsists entirely on phytoplankton. Schaefer ('54) observes, furthermore, that the latter species has been found in great abundance only on broad mud flats, usually at the mouths of rivers, where it grazes on the detritis and microscopic flora associated with these mud flats, particularly on one abundant sessile diatom. It can hardly be doubted that the tapetum offers some advantage in this particular situation, but it is hard to understand how it might be advantageous to the voracious *Lycengraulis.*

It can be seen in table 14 that there are noticeable differences between species in the densities of rods, cones and secondary neurons, and also in the eye size of the specimens. Each of these variables has its particular effect on visual capacity of a species, but quantitative observations are as yet too few and scattered to have yielded precise indices. However, the differences among the six species studied, along with data reported in the literature for a few other species, suggest certain relationships which are discussed below.

Differences in eye size mean that densities of cells cannot be used directly as indices of visual capacity. The size variable must be accounted for in making comparisons between individuals of the same species as well as in making comparisons between individuals of different species. Due to the proportionality of the teleost eye as expressed in Matthiessen's ratio (distance from lens center to retina is 2.55 times the lens radius or 1.275 times the diameter) the diameter of the lens can be used as a convenient basis for making comparisons of the number of cells per unit area in the retina. Pumphrey ('61) has recently pointed out that his own measurements and those of others show that Matthiessen's ratio applies very well to both fish and cephalopods, except that in fish there is evidence that the retina is ellipsoidal rather than hemispherical so that there is a slight departure from Matthiessen's ratio, probably only in the temporal region. Baylor and Shaw ('62) find a similar ellipsoidal shape in the retina of the alewife, *Alosa pseudoharengus*, but their measurements also suggest that the lens to retina distance departs slightly from Matthiessen's ratio — perhaps by some tenths of a millimeter with a lens diameter of nearly 6 mm — over the entire retina. Though these small differences raise some important questions in regard to optical accommodation, they are not enough to invalidate the use of the lens diameter as a size basis for comparing the densities of various kinds of cells in the retina.

Matthiessen's ratio implies that the effective index of refraction of all teleost lenses is the same. Pumphrey ('61) has shown that minnow lenses are aplanatic (free of detectable spherical aberration) and have focal lengths equivalent to Matthiessen's ratio. From this and other considerations he concludes that the index of refraction falls from 1.52 at the center of the lens to 1.33 at the surface and that some mechanism must exist whereby refractive indices of both the inner and the outer parts of the lens are continually and differentially adjusted with growth.

Image size is critical, of course, in any consideration of visual acuity, because the latter depends on the number of cones over which a particular image is spread, but it should have little or no effect on visual sensitivity. Visual sensitivity depends on three things — the proportion of photons emanating from an object that are collected by a lens, the degree to whcih they are concentrated on the retina and the efficiency with which they are absorbed by the rhodopsin screen. It has already been suggested that the absorption by the rhodopsin screen is better ir engraulids than in the other four sp because of the tapetum. Otherwise Walls ('42) states, "The illuminatio the retina will . . . have the same stre in any and all eyes whose proportion exactly the same, *regardless of thei solute sizes*," and teleost eyes do hav same proportions (Matthiessen's ra Thus concentration of photons on retina is constant because improved collecting ability of larger lenses is al offset by the area over which the will be spread on the retina.

Since illumination of the retina is a variable, differences in rod density ably approximate some real differenc sensitivity, particularly since the rod segments (which contain the photos tive rhodopsin) are about the same in the six species described. It is imr ately obvious from table 14 that rod sities in all cases are lower tempo where cone densities are highest. S nops, which in fact has a cone de considerably higher than the others ir ventro-temporal quarter, lacks rods tirely in this part of the retina. Th what might be expected, since it is monly accepted that bright light v takes precedence over dim light vi and that rods will occupy whatever s is left to them by the cones.

Except for the extreme case of S *nops*, rod densities do not show a clear inverse relationship with cone sity. *Alosa* is too low and *Engrauli* high. A higher than expected ve temporal rod density in *Engraulis* is sistent with the specialization for dued-light vision suggested earlier. noteworthy, also, that the visual cell of *Engraulis* is thicker than that in somewhat larger eye of *Sardinops* an most as thick as those in the much la eyes of *Alosa*, *Trachurus* and *Pneur phorus*. This suggests that the retin *Engraulis* is structurally specialize accommodate a relatively great rod r and is a further indication of specia tion for subdued light vision.

Spectrophotometric studies of rod v pigments suggest that the specializatio these two engraulids might be for visio the dim light of turbid coastal water r in the dim light of deeper but clear n water. Munz ('58) has shown that *hoa compressa* is one of several tele- from coastal and estuarine waters have photosensitive rod pigments with rption maxima approaching the green- w portion of the spectrum, which is range of maximum light transmission urbid water. In contrast to this, a ber of deep-sea fishes that have been stigated have absorption maxima in blue portion of the spectrum, which is wn to be the range of maximum light smission in clear ocean water.

one densities, particularly estimates of maximum density, in the retinae of es are often used as an indication of erences in visual acuity without re- l to differences in the size of the eyes lved. It has been shown that cone sity declines appreciably with growth oth *Sardinops* and *Pneumatophorus.* same has been shown for *Lebistes culatus* (Müller, '52) and *Salmo trutta* all, '57a), and Tamura ('57) found the smaller of two specimens of *Lateo- ax japonicus* had the higher cone den- in the temporal region. Examination he data shows that in all of these cases decline in cone density is less than ugh to compensate for the calculated ansion of image area on the basis of thiessen's ratio. A unit image would spread over an increasingly greater nber of cones as the eye enlarged. ner visual acuity changes with eye wth or eye proportionality is an in- ficient basis for the derivation of image a.

Even though the variables that affect ity are not entirely understood, cone nsity and lens size are certainly two of major factors. Figure 19 shows the ressions of double cone density on lens meter for *Sardinops* and *Pneumato- rus,* and also the single dorso-nasal l ventro-temporal values for the other r species described in this report. The sal densities for *Alosa, Engraulis,* and *choa* are very close to the regression e for *Sardinops,* while those of *Trachu-* and *Pneumatophorus* are at a notice- y higher level. The double cone den- es in the temporal region, which are imates of the maximum densities of the retina, show a much greater variation. All species have lower values than *Sardinops.* It is clear that the two engraulids have much lower values than *Sardinops* specimens with eyes of comparable size, but it is not so clear that *Alosa, Trachurus* and *Pneumatophorus* have values that would be different from those of *Sardinops* specimens with comparably large eyes.

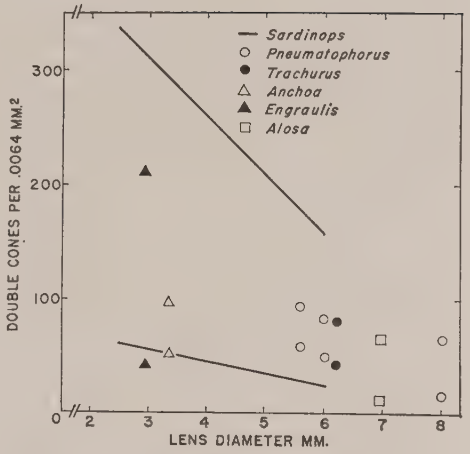


Fig. 19 The number of double cones per 0.0064 mm² in the dorso-nasal and ventro-temporal quarters of the retinae of six teleosts. The lines for *Sardinops* are those fitted to the data given in table 2. Pairs of points given for other species were each obtained from an individual specimen. Values for the ventro-temporal quarter are from the segments with the highest average density.

It is possible that there is some general relationship between cone density and maximum eye size that must be understood before valid comparisons of acuity can be made on the basis of eye structure. The only clue to this in the present data is the fact that the level of the temporal or maximum cone density tends to be lower for the species with the largest eyes.. It is doubtful that *Sardinops* ever attains a lens of more than 6 or 7 mm while *Alosa, Trachurus* and *Pneumatophorus* probably attain lens diameters of 12 to 14 mm. The two engraulids do not conform to this pattern because they have lower values than *Sardinops,* although they probably never attain lens diameters of more than about 4 mm. It must be recalled at this point that several other features of the engraulid eyes suggest that they are specialized primarily for vision in subdued light, and that relatively low visual acuity would not be inconsistent with such a pattern.

It can only be said, then, that *Engraulis* and *Anchoa* very likely have lower visual acuities than *Sardinops*, but that it is difficult to evaluate the differences in cone density between the smaller *Engraulis*, *Anchoa*, and *Sardinops* and the larger *Alosa*, *Trachurus* and *Pneumatophorus*. At the same time the higher levels of nasal cone density in *Trachurus* and *Pneumatophorus* suggest that visual acuity is more nearly uniform over the entire visual field of these fishes than it is in the four clupeoids.

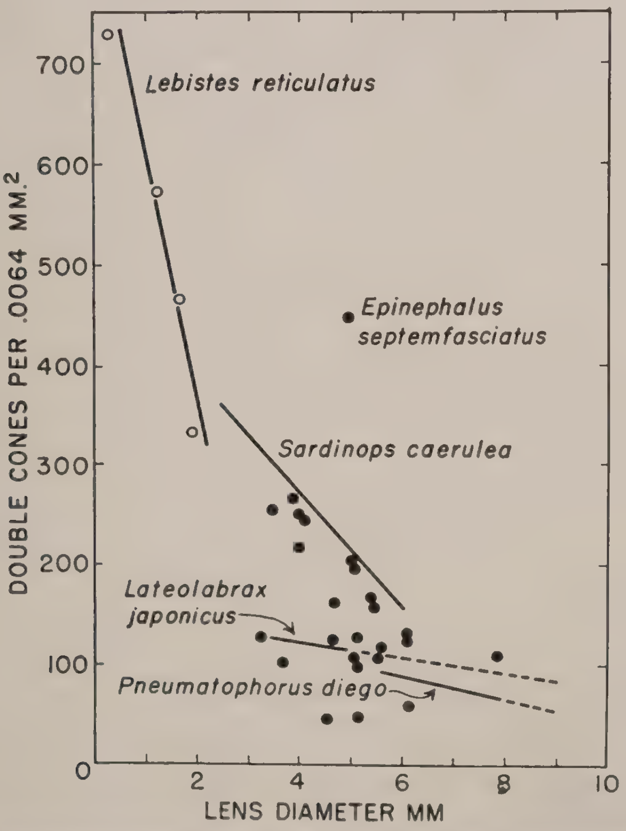
Variations in cone density have been discussed in terms of the double cones because they are the predominant cone type in the eyes of these fishes, and for that matter in the eyes of teleosts in general. It is interesting to note, however, that the distributions of single cones in a sense reenforce the differences apparent in the distributions of the double cones. As already mentioned, the engraulids, which appear to have relatively low double cone visual accuity, do not have single cones at all. The clupeids, which have considerably better double cone acuity in the *area temporalis* than elsewhere in the retina, have single cones uniformly half as abundant as the doubles in the *area*, whereas they are irregularly distributed and much less abundant over the rest of the retina. In *Trachurus* and *Pneumatophorus*, where double cone acuity does not change very much over the retina, the single cones are uniformly half as abundant over the entire retina. The only exception is that in *Pneumatophorus* the singles are equally as abundant as the doubles in the dorso-temporal quarter. As pointed out earlier, Tamura ('57) found equal abundance of the two types in *Scomber japonicus*, which is a member of the family Scombridae, as is *Pneumatophorus diego*. The relatively high abundance of single cones suggests that these two species, and perhaps the family Scombridae, are somewhat better equipped for vision in the brightest region immediately beneath the surface than *Trachurus* or the four clupeoids described in this report.

The degree of eye mobility, whic
probably important in stabilizing the
ual environment relative to the movem
of the fish, is indicated by the dev
ment of the anterior rectus muscle.
differences among the species desc
in this report relate in a reasonable
ner to what has already been infe
about their visual acuity. The engrau
which appear to have lower acuity
the others, have vestigial *anterior*
and probably make relatively slight
pensatory movements of the eye in
horizontal plane. The obliques are
erately well developed on these fishes
aligned so that they would affect
pensatory "wheeling" movements of
eye; it is doubtful that they could e
tively replace the function of the *ant*
rectus. The clupeids, which have
tively high acuity and moderate *ant*
recti, probably make greater compe
tory movements. *Trachurus* and *Pne*
tophorus, though they may not have hi
acuity than the clupeids, have essent
the same acuity over the entire fiel
vision, and their well developed *ant*
recti suggest they probably make r
extensive eye movements to stabili
rapidly shifting visual environment
may well be that the entire retina
these two species is functionally
parable to the restricted *areae tempo*
of the clupeoids.

Though the labeling of a region of
retina as an *area temporalis* is r
arbitrary, it is clear that all of the a
species have higher cone densities in
temporal region than elsewhere: Pump
('61) on the basis of the elliptical s
of the retina described by Lyall ('57a
Salmo trutta, advanced the hypothesis
teleosts may be hypermetrophic ove
but the forward part of the visual
where the longer lens-to-retina dist
would make them myopic. He sug
that small objects in front of and
to the fish would thus be in focus
in other parts of the field large ob
would be in focus at infinite distance
commodation by retraction of the
would only be necessary if objects in
of and at some distance from the fish
to be brought into focus. The occur
of higher cone density in the portic

retina that subtends the forward part
ie visual field would be consistent with
an hypothesis. In fact the ability to
lve smaller objects near or far in the
ard part of the field would require a
ied cone screen in the temporal part
ie retina.

hen the maximum double cone den-
s for *Lebistes* (Müller, '52) and 26
nese species (Tamura, '57) are com-
d to those already presented for
inops and *Pnepmatophorus* (fig. 20),
suggestion of a basic relationship be-
n level of cone density and maximum
size is still evident. *Lebistes*, which
a much smaller maximum lens diam-
than any of the species previously discussed, also has a much higher range of cone densities. Even the two specimens of *Lateolabrax japonicus* conform to this pattern. The species is known to reach a length of more than 900 mm (Okada, '55), at which size it must have a lens diameter approaching that of *Pneumatophorus*. Though the level of cone density is slightly higher than that of *Pneumatophorus*, the slope of the change is about the same. In all probability acuity is similar in *Lateolabrax* and *Pneumatophorus*, but without a better understanding of the factors involved it is difficult to know whether acuity in these species is really any different from what it is in the smaller *Sardinops* and the even smaller *Lebistes*.



g. 20 The estimated maximum number of double cones per 0.0064 mm^2 in the ventro-tem-
l quarter of 29 teleosts. The data for *Sardinops caerulea* and *Pneumatophorus diego* are from this
rt. The data for *Lebistes reticulatus* are from Müller ('52). The individual points are based on
given by Tamura ('57) for 26 species. Only two of the latter are labeled.

The only other species worthy of comment at this point is *Epinephalus septemfasciatus*. The double cone density is comparable to that of *Lebistes*, but the lens is much larger than is ever attained by *Lebistes*. More interesting still is the fact that *E. septemfasciatus* is known to attain a body length of at least 400 mm (Okada, '55). The cone density in figure 20 is taken from a specimen 140 mm in length with a lens diameter of 5 mm so it is likely that the species has a maximum lens diameter of 9 to 12 mm. Since this is similar to the maximum lens diameters of *Pneumatophorus* and *Lateolabrax*, it would be most interesting to know whether the regression of cone density on lens diameter for *E. septemfasciatus* would approximately parallel those of the other two species. If so, the differences in level might indicate real differences in acuity among them as well as some suggestion of the variation that can be expected in the cone density-lens diameter relationship among telosts.

A number of workers report the a
dance of secondary neurons along
the abundance of visual cells in the re
of teleosts, usually implying that v
acuity is better when neuron abund
is relatively high. Svaetichin and
Nichol ('58) note that animals ha
higher visual acuity than fishes also
a greater concentration of neurons
unit of retinal area, which supports
implication of higher acuity with hi
neuron abundance. Polyak ('57) has
onstrated for primates that these cells,
distinctive although complex and h
ramified synaptic relationships with
other and with the visual cells.
synaptic complexes undoubtedly serv
elaborate and integrate the impulses
transmitted from the visual cells to
higher centers in the brain. It may
be, then, that greater abundance of
rons relative to the abundance of c
means greater retinal integration
perhaps better acuity.

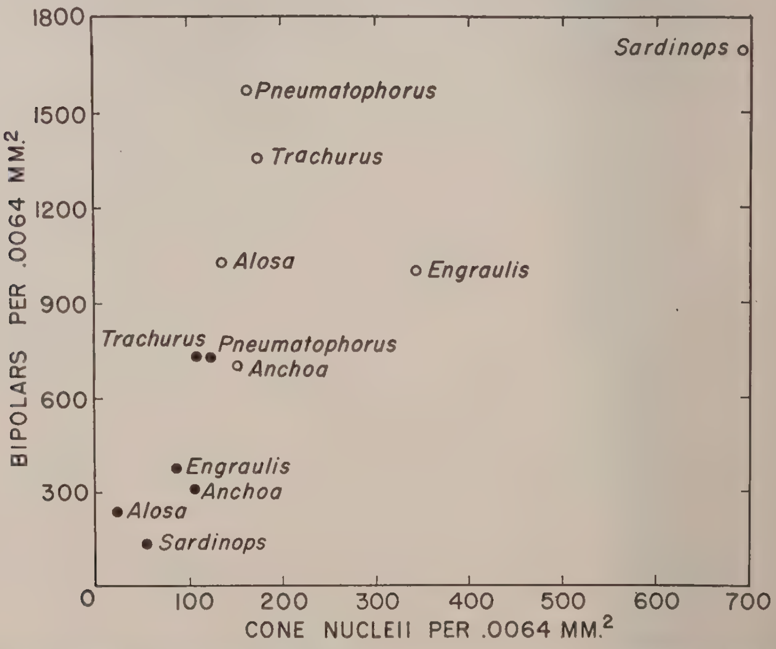
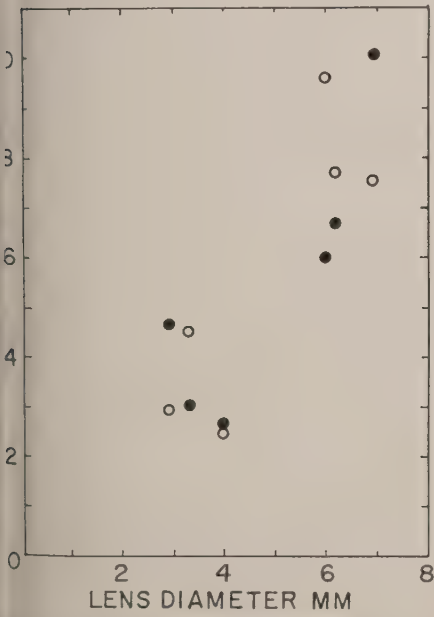


Fig. 21 The number of bipolars per 0.0064 mm² on the number of cone nucleii per 0.0064
for six teleosts. The solid circles represent the nasal arc and the open circles represent the
poral arc.

olars are far more abundant than kinds of neurons in the retinae of ix teleosts described in this report, ey are in the vast majority of verte- s. When their dorso-nasal and ventro- oral densities (table 14) are plotted st the appropriate densities of cone i (number of double cones doubled he number of single cones) (fig. 21), n be seen that bipolar density in- es with cone nuclei density but that is wide variation among the higher s. The nature of this variation sug- that *Alosa, Trachurus,* and *Pneuma- orus* have more bipolars per cone us in the temporal region than *Sardi-* or *Engraulis,* which have much er cone densities. The other obvious rence between these two groups is eye or lens diameter. When the number ipolars per cone nucleus is plotted nst lens diameter (fig. 22). it appears crease in a general way with lens eter for both the nasal and temporal ions.



ig. 22 The number of bipolars per cone nu- s on lens diameter for the six teleosts de- ed in this report. The solid circles represent nasal arc and the open circles represent the poral arc.

The increase with lens diameter suggests that neural complexity expands primarily to maintain image integration as image area expands. The data presented here are not an adequate demonstration of this, of course, but they do raise some question about the view that visual acutiy varies with bipolar (or neuron) density.

It has been shown in this discussion that more comparative information is needed on the retinae of teleosts before the numbers and arrangement of their visual cells can be used as indices of visual acuity and visual sensitivity. The comparisons do suggest, however, that there is some interspecific relationship between cone density and eye size in teleosts that may be clarified by examination of additional species representing the full range of sizes from both the pelagic and demersal habitats.

There is rather compelling evidence that the two engraulids, and perhaps the entire family Engraulidae, are more specialized for vision, or at least some functions involving vision, in subdued light than the clupeids or *Trachurus* and *Pneumatophorus.* This needs to be studied experimentally to determine what advantages the engraulids enjoy in subdued light situations and whether or not they have real preferences for any such situations.

Experimental studies involving the six species described in this report, which have very different single cone complements, might also provide further insight into the functional differences between double and single cones. Such information would establish a firmer basis for interpretation of retinal function in all teleosts.

SUMMARY

A. The eyes of *Sardinops caerulea, Alosa sapidissima, Engraulis mordax, Anchoa compressa, Trachurus symmetricus,* and *Pneumatophorus diego* are described in turn. The detailed descriptions of retinal density distribution of cones, rods and neurons are taken from one specimen of each species. The relation of cone density to eye growth was determined from a series of specimens for *Sardinops caerulea* and *Pneumatophorus diego.* Additional specimens of all species were examined to describe the retinal photomechanical changes that occur in the processes of light and dark adaptation.

B. A comparison of the descriptions shows the following:

1. All species have both good cone systems and good rod systems; in all cases the cones are most abundant in the ventro-temporal quarter of the retina and the rods most abundant in the nasal half of the retina.

2. The two engraulids have occlusible retinal reflecting mechanisms. This suggests that they are better equipped than the others for vision in dimly lit or turbid environments.

3. The two engraulids do not have single cones. Circumstantial evidence suggests that fish lacking single cones are not as well equipped for vision in very bright light as those that have both double and single cones.

4. Cone density at two retinal locations is shown to decline with increasing eye size in *Sardinops caerulea* and *Pneumatophorus diego;* the same is known to occur in some other species, so cone densities of single specimens do not provide an adequate basis for evaluating visual acuity.

5. The data suggest that the level of ventro-temporal double cone density tends to be lower in species that attain the greatest eye sizes.

6. The data suggest that the two engraulids may have lower visual acuity than *Sardinops*, but the differences between the smaller *Engraulis*, *Anchoa* and *Sardinops* and the larger *Alosa*, *Trachurus* and *Pneumatophorus* are not amenable to interpretation; more information on the relation between cone density and eye growth in teleosts is needed.

7. Double cone density is higher in the nasal region and more uniform over the retina in *Trachurus* and *Pneumatophorus* than in the four clupeoids. This indicates that *Trachurus* and *Pneumatophorus* have nearly uniform acuity over the entire visual field, while the four clupeoids have noticeably better acuity in the forward part of the visual field than elsewhere.

8. Single cones, which are en
lacking in the engraulids, occur
ratio of one to two with double c
only in the ventro-temporal quart
the clupeid retina, and essentially
the entire retina of *Trachurus*
Pneumatophorus. This suggests
the latter two species are relatively
equipped, and the engraulids relat
poorly equipped for vision in b
light.

9. Differences in the insertion
thickness of the anterior rectus m
indicate that horizontal eye mobili
probably greatest in *Trachurus*
Pneumatophorus and poorest in
engraulids.

10. The number of bipolar cells
cone nucleus tends to vary with
size among these species, sugge
that the complexity of neural int
tion in the retina varies with rel
image area.

ACKNOWLEDGMENTS

The author wishes to express his th
to the late Dr. Gordon Walls of the
versity of California, Berkeley, to
Frederick Crescitelli of the Universit
California, Los Angeles, and to Dr. F
erick W. Munz of the University of Ore
Eugene, for their helpful comments
suggestions in reviewing the present w

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Abbreviations

D. Double cone
L. Limitans
R. Rods
S. Single cone
e. ellipsoid
f. fuscin granules
g. guanin
m. myoid
n. nucleus

PLATE 1

EXPLANATION OF FIGURES

All figures are phase photographs of unstained tangential sections of retinae. The two figures for each species are from the same eye of one specimen. × 1,100.

23 *Sardinops caerulea,* lens diameter 4.00 mm, dorso-nasal quarter.

24 *Sardinops caerulea,* lens diameter 4.00 mm, ventro-temporal quarter.

25 *Engraulis mordax,* lens diameter 2.92 mm, dorso-nasal quarter.

26 *Engraulis mordax,* lens diameter 2.92 mm, ventro-temporal quarter.

27 *Alosa sapidissima,* lens diameter 6.95 mm, dorso-nasal quarter.

28 *Alosa sapidissima,* lens diameter 6.95 mm, ventro-temporal quarter.

29 *Anchoa compressa,* lens diameter 3.35 mm, dorso-nasal quarter.

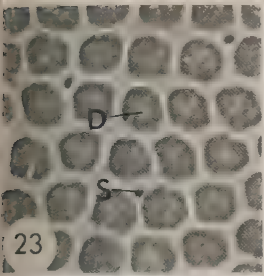
30 *Anchoa compressa,* lens diameter 3.35 mm, ventro-temporal quarter.

31 *Trachurus symmetricus,* lens diameter 6.20 mm, dorso-nasal quarter.

32 *Trachurus symmetricus,* lens diameter 6.20 mm, ventro-temporal quarter.

33 *Pneumatophorus diego,* lens diameter 6.00 mm, dorso-nasal quarter.

34 *Pneumatophorus diego,* lens diameter 6.00 mm, dorso-temporal quarter instead of ventro-temporal quarter to illustrate the 1:1 ratio of single to double cones.



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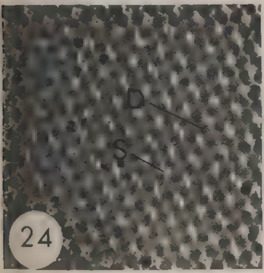

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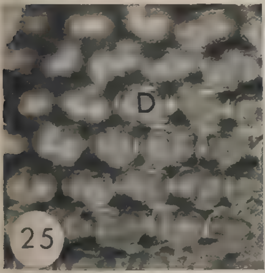

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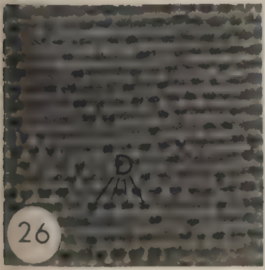

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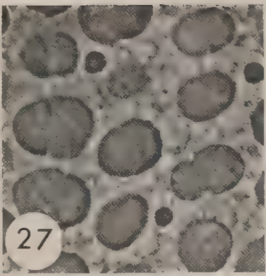

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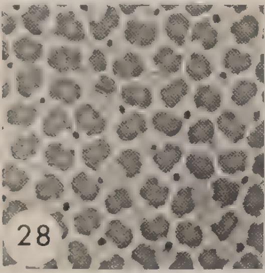

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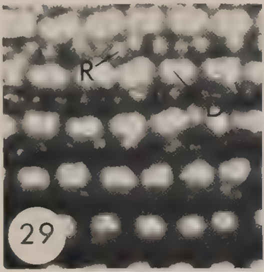

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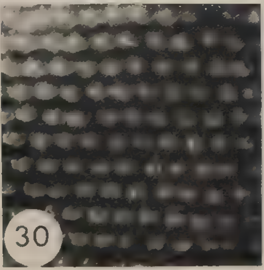

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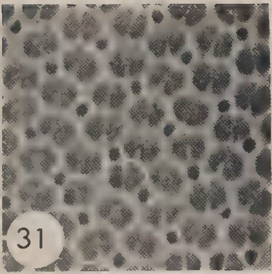

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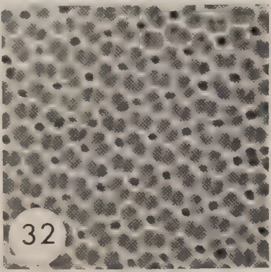

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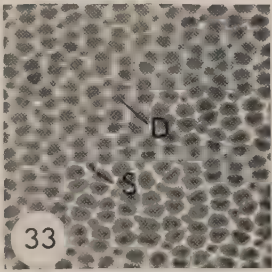

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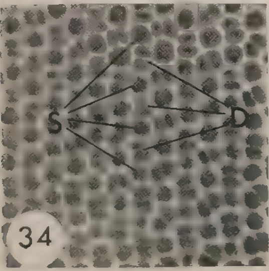

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PLATE 2

EXPLANATION OF FIGURES

All figures are photographs of cross sections of retinae. Each matching pair is from the same eye of one specimen. × 2,400.

35 *Sardinops caerulea,* dorso-nasal quarter, light adapted, stained with H. and E.

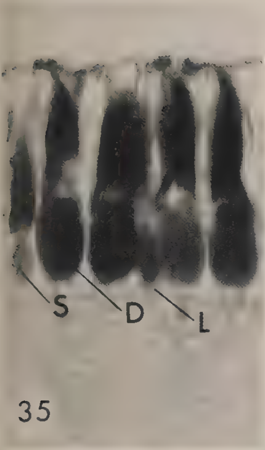
36 *Sardinops caerulea,* ventro-temporal quarter, light adapted, H. and E.

37 *Sardinops caerulea,* ventro-temporal quarter, dark adapted, H. and E.

38 *Sardinops caerulea,* dorso-nasal quarter, dark adapted, H. and E.

39 *Alosa sapidissima,* dorso-nasal quarter, light adapted, unstained, phase microscopy.

40 *Alosa sapidissima,* ventro-temporal quarter, light adapted, unstained, phase microscopy.



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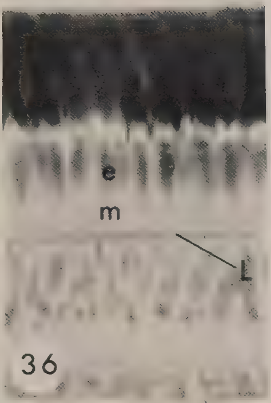

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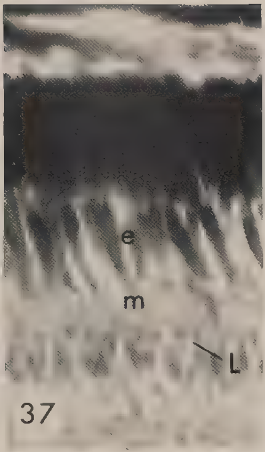

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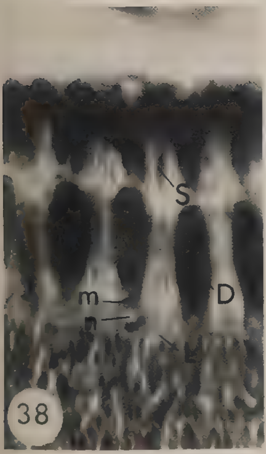

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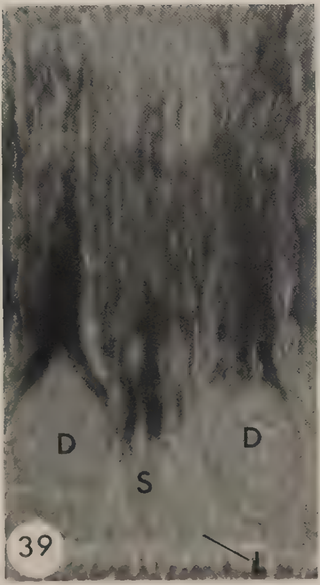

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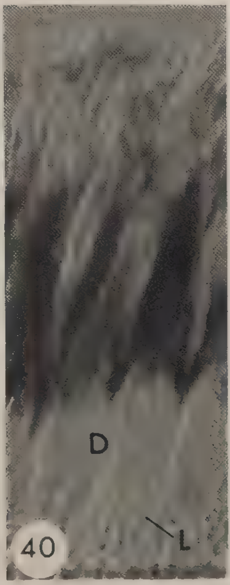

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PLATE 3

EXPLANATION OF FIGURES

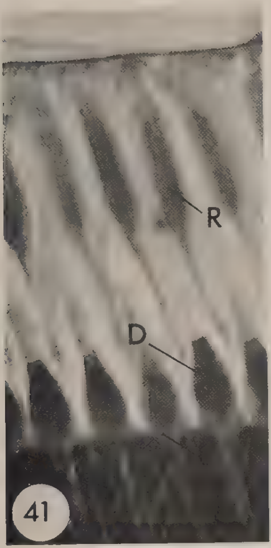
All figures are photographs of cross sections of retinae of *Engraulis mordax,* dorso-nasal quarter. × 2,400.

41 Light adapted with the pigment extracted from the pigment cells to show the visual cells. Stained with H. and E.

42 Light adapted, showing the dispersion of fuscin granules through the guanin in the pigment cell processes. Unstained, phase microscopy.

43 Dark adapted, with the pigment extracted from the pigment cells to show the visual cells. Stained with H. and E.

44 Dark adapted, showing the withdrawal of the fuscin granules to the bodies of the pigment cells. Unstained, phase microscopy.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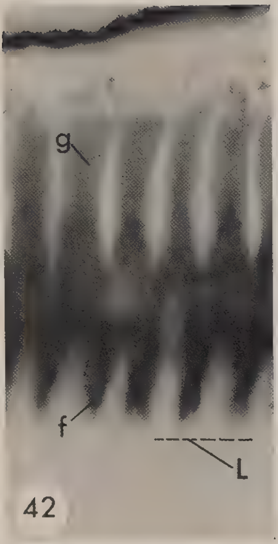
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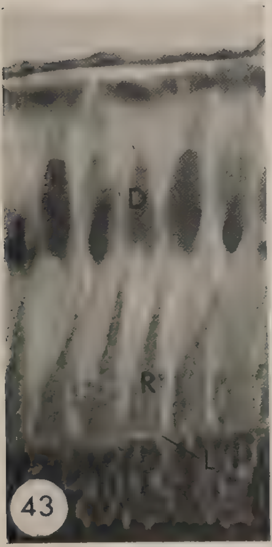
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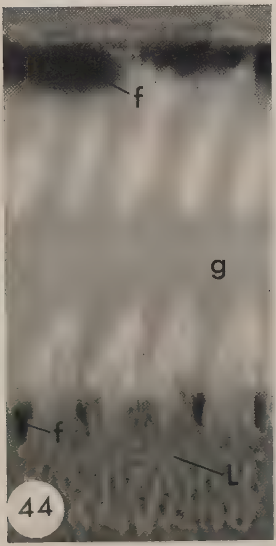
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PLATE 4

EXPLANATION OF FIGURES

All figures are photographs of cross sections of retinae. × 2,400.

45 *Engraulis mordax,* ventro-temporal quarter, light adapted, with pigment extracted from the pigment cells to show the visual cells. Stained with H. and E.

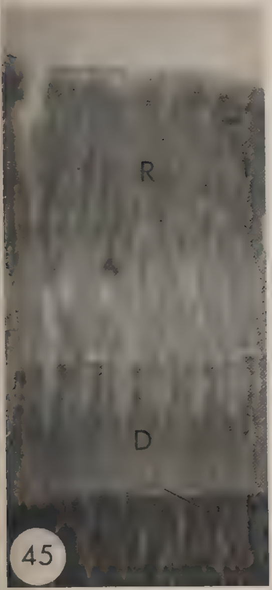
46 *Engraulis mordax,* ventro-temporal quarter, light adapted, showing the dispersion of fuscin granules through the guanin in the pigment cell processes. Unstained, phase microscopy.

47 *Engraulis mordax,* ventro-temporal quarter, dark adapted, with pigment extracted to show the visual cells. Stained with H. and E.

48 *Engraulis mordax,* ventro-temporal quarter, dark adapted, showing the withdrawal of the fuscin granules to the bodies of the pigment cells and the concentration of the guanin towards the tips of the pigment cell processes. Unstained, phase microscopy.

49 *Anchoa compressa,* dorso-nasal quarter, light adapted, showing the dispersion of the fuscin granules through the guanin in the pigment cell processes. Unstained, phase microscopy.

50 *Anchoa compressa,* ventro temporal quarter, light adapted, showing the dispersion of the fuscin granules through the guanin in the pigment cell processes. Unstained, phase microscopy.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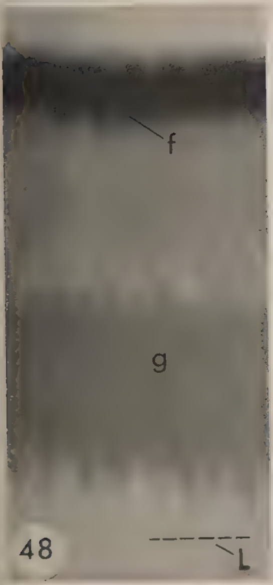
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PLATE 5

EXPLANATION OF FIGURES

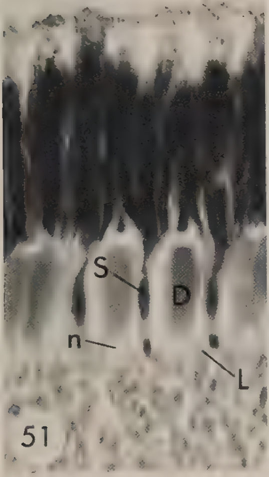
All figures are photographs of cross sections of light adapted retinae stained with H. and E. × 2,400.

51 *Trachurus symmetricus,* dorso-nasal quarter.

52 *Trachurus symmetricus,* ventro-temporal quarter.

53 *Pneumatophorus diego,* dorso-temporal quarter.

54 *Pneumatophorus diego,* dorso-temporal quarter where single and double cones are in 1:1 ratio.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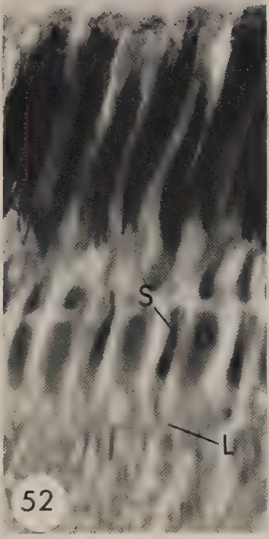
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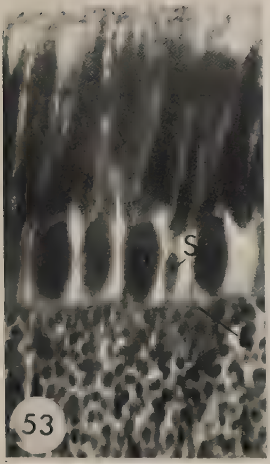
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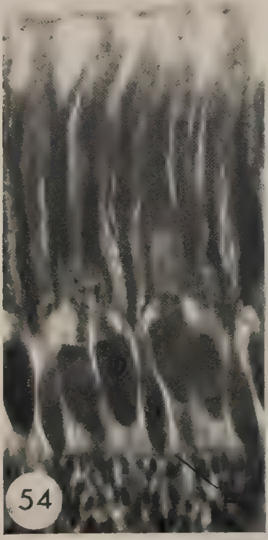
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Reprinted from Limnology and Oceanography
Vol. 8, No. 2, April, 1963
pp. 297–298

Trailing Incubator for Studies of C^{14} Uptake by Phytoplankton

Shipboard use of the C^{14} method of easuring primary production, first de- ribed by Steemann-Nielsen (1952), in- lves incubation of inoculated samples her *in situ* or in an illuminated incu- tor. Conditions imposed by lack of time space may necessitate sea-surface incu- tion of samples by trailing them on a ngth of line in the wake of the research ssel. Problems arising from this method clude data loss due to bottle breakage d "frozen" glass stoppers, as well as in- nvenience of manipulation. The trailing cubator described below minimizes these ficiencies.

The incubator body is a molded lucite be with an inside diameter of 2¼ in., ⅛- . wall, and 36-in. overall length if six 125- l bottles are housed. Tubing with larger iameters is commonly available for 250- nd 500-ml bottle accommodation. The ading end of the tube is beveled to 45°. einforcing collars (Fig. 1A, B) are formed y cementing appropriately shaped tube egments of 2½-in. inside diameter around e leading and trailing ends of the incu- ator.

To provide lateral stability, a lucite fin, in. deep, is cemented to the bottom side f the trailing end (Fig. 1C). Reinforcing f the fin is provided by a split lucite rod f 1-in. diameter which previously has een milled along its axis to conform to e outside curvature of the incubator tube Fig. 1D).

The towing assembly (Fig. 2) consists of 2 heavy-duty brass hose clamps (2½-in. inside diameter), a flat brass bar, and a smaller brass bar. The larger bar is bent 45° from horizontal and the smaller bar is silver-soldered to it. Two holes are drilled at this union for insertion of hose clamp bolts, and one hole is drilled at the distal end of the longer bar for towing-shackle insertion.

As the hose clamps are rather inflexible, they are slipped onto the incubator tube before the last reinforcing collar is cemented to the tube. Hose clamps are tightened until the assembly is firmly seated. The towing bar is extended in the direction of towing and the long end of the tube bevel is oriented forward and beneath the tube axis to act as a "scoop." The towing assembly is placed initially as far forward on the tube as the front collar allows, and then adjusted rearward as needed.

Cups made by cutting tops off 4-oz polyethylene bottles are inverted over the flat-stoppered mouths of the sample bottles and seated on the bottle shoulders to serve as cushions. Clearance between stoppers and cup bottoms prevents breakage and reduces "frozen stopper" occurrence. The foremost cushion (Fig. 1F) is transfixed to the tube by the forward retaining bolt (see below). Clearance is provided between the stopper of the first bottle and the retaining bolt by making the cushion long enough.

Bolts are inserted through diameters of the tube before and behind the sample

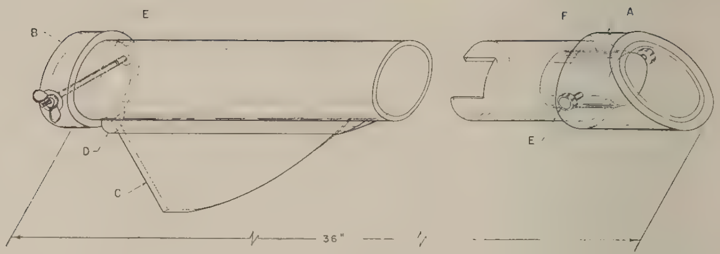


FIG. 1. Constructional details of main body, showing (A) front reinforcing collar, (B) rear reinforcing collar, (C) stabilizing fin, (D) fin support, (E) bottle retaining bolts, (F) foremost cushion (isometric).

bottles to retain the bottles in the incubator (Fig. 1E). The rearward bolt is inserted through holes drilled in the reinforcing collar since the brunt of the force exerted by water flow on the bottles is borne by this bolt. With the rearward bolt in place, bottles with their polyethylene cushions are placed in the tube to determine positioning of the forward bolt through the front reinforcing collar. This insures a snug fit.

The incubator is "breech loaded" with inoculated samples alternated with cushions by slipping the rearward bolt from its seat and placing bottles and cushions in the tube. The dark bottle, used as a control, should be placed in the shadow of the towing assembly. Depressing the last bottle with the thumb permits the bolt to be reinserted. The wing nut is replaced finger-tight. The incubator is affixed to a towing line. The length of towing line is adjusted to reduce porpoising and lateral movement. Upon recovery, the incuba is detached from the towing line and c ried intact to the laboratory.

Suggestions provided by R. W. Holm and R. W. Gilkey of Scripps Institution Oceanography, and by E. D. Forsbergh the Inter-American Tropical Tuna Co mission are gratefully acknowledg Holmes also suggests that neutral scre filters could be wrapped around the in bator to reduce illuminance to that fr which subsurface samples are commo obtained, although this feature is not corporated in the present design.

REFERENCE

STEEMANN-NIELSEN, E. 1952. The use of rad active carbon (C^{14}) for measuring orga production in the sea. J. Cons. Inte Explor. Mer, **18**: 117–140.

R. W. OWEN,
U. S. Bureau of Commercial Fisheries, Biological Laboratory, San Diego, California.

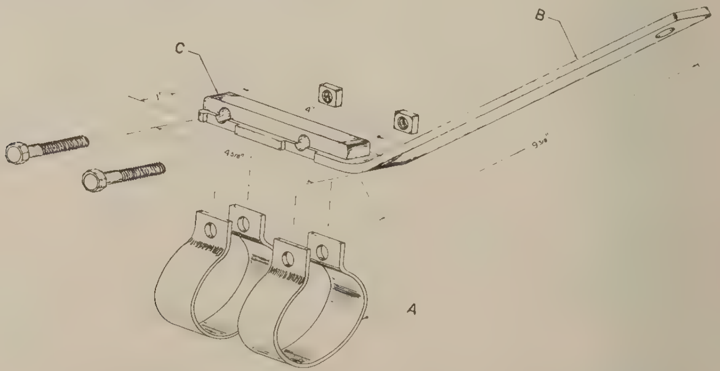


FIG. 2. Constructional details of towing assembly, showing (A) galvanized hose clamps, (B) towing bar, (C) bolt retention bar (isometric).

~~ıe numbers of circuli and width of the zones und to differ for the freshwater portions of the However, the width of the zone which was ed during the first year at sea was found to be om this difficulty. Fish with different fresh- ages should be considered separately for all scale characters because the scale character are significantly different depending on the ater age. Such groups can not be combined. equired that separate systems be developed for roup if freshwater zones of the scales are to be identify the origins of fish taken at sea.~~

~~n one to four years are spent at sea, with most maturing fish having either two or three zones r scales (each zone represents one year of ocean ce). Tests of this source of variation show ıly the width of the total freshwater zone can d to determine the origins of high seas samples ıing fish of different ocean ages. To use other ters, the samples should first be separated ing to the number of years spent at sea.~~

~~single discriminant is to be appropriate for ying the origin of salmon found at sea, the haracters used must be constant for successive years. Fish of different brood years are mixed t sea and in the spawning runs, so this source ation cannot be ignored. No scale characters uitable for combining brood years.~~

~~following can be concluded from these scale s:~~

~~The average error in determining the ages of d salmon by three trained personnel was 13 t per reader. This difference did not affect the accuracy of circuli counts and measurements of scale width.~~

~~2. A scale axis can be selected with an average deviation of plus or minus two degrees and a maximum expected deviation of plus or minus ten degrees. No bias is introduced by this amount of variation.~~

~~3. It is important to always use the same scale axis to measure and count scale characters. Deviations could cause error in determining the origin of fish taken at sea.~~

~~4. The body zone from which a scale is taken is important. Some scales taken from body area C below the lateral line are questionable for determining ages. Scales from body area A are acceptable for determining scale characters.~~

~~5. Sampling dates can be ignored as a source of variation for Bristol Bay rivers.~~

~~6. No difference was found between scales from male and female fish in measurements or circuli counts in the freshwater zone, or in the part of the scale reflecting the first year of sea life. Data for males and females can be combined for these scale characters.~~

~~7. The circulus count and scale width of the first ocean zone was found to be free of differences arising from variations in freshwater age and growth patterns.~~

~~8. Only the total freshwater scale length is free from variations connected with differing ocean ages.~~

~~9. Brood year differences occur for all scale characters, and brood years are a definite source of variation.~~

PINK SALMON STUDIES

by Roger E. Pearson

ee morphological characters were obtained salmon collected in 1957 and used for a pre- ry study to examine their utility in separating from North American pink salmon in offshore es. Results were reported in Amos *et al.* (1960). found that North American pink salmon from ing areas south of Kodiak Island and Cook were distinguishable from pink salmon of the Asian spawning areas. The characters could parate pink salmon of the Alaska Peninsula, an Islands and northwestern Alaska from those of Kamchatka. Since it is probable that these North American fish are present in the high seas samples, additional research to obtain their separation was initiated. This research was directed toward two goals: the first was to examine a set of new scale characters to determine their suitability for use in the separation analysis of 1959 samples, the second was to classify correctly all 1959 North American inshore samples to their natal continent and identify the origins of the fish in the 1959 high seas samples.

ternational North Pacific Fisheries Commission, Annual Report 1961,
ncouver, Canada, 1963, p. 116-119.

plate and the circuli form concentrically around this plate as the scale grows. Since the central plate is common to all scales, it can be used as a starting point to determine scale characters and factors that could affect scale character values.

Using the central plate as a focus, radii can be drawn at different angles across a scale and scale character determinations can be made on lines at these angles. The question arises, however—are scale character values different depending on the scale angle that is used? If scale character values do change when determined at different angles, and if this affects assignment to continent of origin, then the scale angle used to determine scale character values should be consistent. The first step in testing scale angles is to see if a consistent axis of the scale can be chosen. This is important because the precision of selecting any particular angle of the scale must be known before the data can be considered reliable. It was determined that the freshwater axis (which was chosen by visually dividing the freshwater zone of the scale into two equal parts and using the mid-line as the axis) could be selected with a precision that did not introduce significant error in the scale character values. Therefore, the freshwater axis was used to establish the selected scale angle. It was found that scale character values differ greatly for a single scale when these values are taken along different radii. Therefore it is necessary to establish precisely the angle of examination.

Red salmon ages are determined visually by personnel trained to interpret the spacing of the circuli of the scale. The accuracy of ages derived from scale reading cannot be known without supplementary information such as tagging or marking experiments, but a test of the consistency of age determinations is possible. Scales from 180 red salmon were examined by three trained personnel separately and age determinations made. A conference was held by the same three persons to derive an "agreed" age for all scales. Using the "agreed" ages, the average error in age determination was 13 percent per reader. This difference did not affect circuli counts or measurements of the total freshwater or first ocean zones.

Scales taken from different body locations might vary in scale character values and in apparent age because they are not all formed at the same time. To test this possible source of variation, a fish from the Naknek River was selected. From a chosen scale (as in Figure 28) it was determined that this fish had migrated seaward in the third year of life and returned to spawn in the sixth year. Some scales taken in

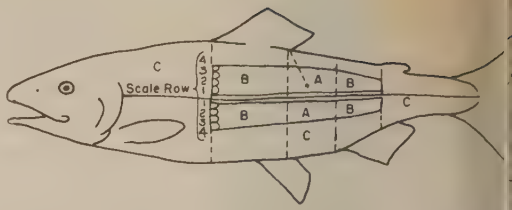


Figure 28. Scale sampling code used by agencies o
INPFC. A* is the preferred scale.
A—preferred area if preferred scale is missing.
B—second choice if scales in area "A" are missing
C—all other scales.
Scales may be taken from either side of the fish,
left side is preferred. (From Proceedings of the
Annual Meeting, INPFC, p. 73.)

body area C (Figure 28) above the anal fin a
the pectoral fin indicated the fish had migrate
ward in the second year and returned to spawn i
fifth year. This suggests that all scales from the
fish do not give the same age reading and that
zone-C scales taken below the lateral line are
tionable for age determinations. Area A and a
scales were tested for the scale characters, and i
found that only area A scales should be used.
sequently we have used only body-zone-A scal
determining scale characters.

Because mature males are usually larger than m
females of the same age, it was considered po
that the variation in body size might be reflect
the scale. However, tests of scale characters sh
no difference between males and females for c
counts and measurements of the first and second
freshwater zones, the total freshwater zone an
first year in the ocean zone. Ratios of circuli c
of these zones were not different between male
females. Characters computed from the rat
freshwater zone radius to the radius of the scale
one and two years at sea) were different bet
sexes.

Intra-seasonal differences were tested by
samples collected on different dates from indiv
Bristol Bay streams. No differences were foun
any of the scale characters. Marked differences
been noted in the scale patterns of red salmon
were taken from different parts of the run of
other than those of Bristol Bay.

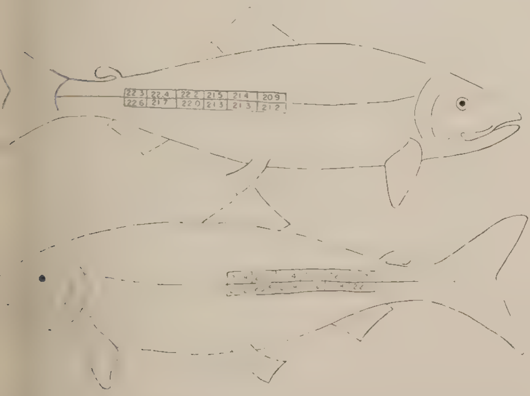
Individual red salmon spend different amou
time in fresh water before migrating seaward.
scale samples were separated according to the nu
of years spent in fresh water and the presen
absence of rapid growth just prior to seaward m

SUITABILITY OF SCALE CHARACTERS FOR USE IN THE SEPARATION ANALYSIS

efore a scale character based on a circuli count or isurement can be used to determine the continent rigin of pink salmon, several important questions st be answered. A determination must be made o whether the scale reader can accurately repeat count or measurement. Do scales from different itions on the body of the fish show the same racters? Are the scale characters the same on e and female fish? Are the scale characters innced by the length of the fish? The following ılts were obtained from testing these possible rces of variation:

. *Ability of a scale reader to repeat his count or meas-nent.* Thirteen scale characters were tested to cover if a scale reader could accurately repeat a vious circuli count or measurement. One charer was dropped from the study for lack of accuracy. e remaining 12 were satisfactory.

. *Differences in counts and measurements of scales n different body positions.* Scales from various body sitions were examined to determine if the mean ues of their characters were similar. If the counts measurements differ, scales from only one part of fish can be used in the separation analysis. The ults indicated all circuli counts follow a pattern ıilar to that shown in Figure 29 where higher mean lues occur in the posterior body positions. Because these differences, only scales from one part of the ı were used in this study.



IGURE 29. Total circuli count in the first year of scales from different body positions. Right and left sides.

3. *Sexual differences in circuli counts and measurements.* ıch character was tested to determine if differences curred between sexes. If no difference was found, the sexes were combined in the samples. If the sexes differed, the character was dropped from the study or retained when differences were considered negligible. Two characters were dropped from the study when they were found to differ between sexes.

4. *Effect of fish length on circuli counts and measurements.* It is not always possible to collect fish with length typical of their race, because certain types and sizes of fishing gear will select fish by length. If the characters being studied are influenced by length, biased samples will occur when specimens of non-representative size are collected. To examine this possibility, tests were performed to determine the relationship between fish length and each of the characters. The results of these tests indicated length of fish had a negligible effect on the circuli counts and measurements.

Thus three of the original 13 scale characters were judged unsuitable and dropped from the study at this point. The remaining ten were judged on their ability to separate North American inshore samples from Asian samples. Four of these ten characters were found to be excellent separators, and these four characters plus two from the previous study were used in separating the 1959 high seas pink salmon samples. The scale characters were taken from the first year's growth zone and are: (1) number of circuli in the first half, (2) number of circuli in the second half, (3) the number of circuli in the second 1/6, and (4) width of the narrowest band of three successive circuli in the first ten circuli. The meristic characters were the number of vertebrae and the number of branchiostegal rays.

CLASSIFICATION OF 1959 SAMPLES TO CONTINENT OF ORIGIN

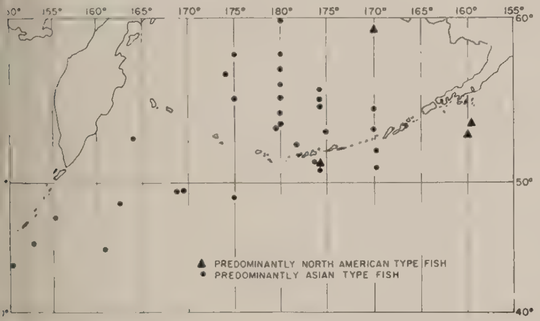
Inshore samples from the Alaska Peninsula, Aleutian Islands and Northwestern Alaska could not be distinguished from Asian fish in the 1957 collections; consequently, if any specimens from these areas were present in the offshore samples, they would have been erroneously classified as Asian. The purpose for choosing the six discriminating characters mentioned in the previous paragraph was to correct this error in classification.

Pink salmon caught on the high seas in 1959 were classified as to continent of origin using a discriminant function analysis. Offshore samples from the east coast of the Kamchatka Peninsula were selected as an Asian standard. The selection of eastern Kamchatka was based on the results of fish tagging experiments, on the large size of coastal Kamchatka catches, and proximity of Kamchatka to the locations of the high seas sampling areas. Five inshore samples from western Alaska were selected for the Nor American standard. These samples were from are close to the high seas sampling locations.

Table 15. Results of 1959 pink salmon classification to continent of origin.

Sampling date	Location of sample	Sample size	Percent classified	
			North American type	Asian type
North American inshore samples				
9/1	Fraser River (British Columbia)	45	100.0	0.0
8/14	Rivers Inlet (British Columbia)	52	100.0	0.0
8/14	Skeena River (British Columbia)	56	100.0	0.0
8/16	Ketchikan (Southeastern Alaska)	26	100.0	0.0
8/18	Ketchikan (Southeastern Alaska)	24	100.0	0.0
8/3	Petersburg (Southeastern Alaska)	47	100.0	0.0
8/9	Petersburg (Southeastern Alaska)	20	100.0	0.0
8/6	Uyak Bay (Kodiak Island)	60	93.3	6.7
7/30	Ivanof Bay (Alaska Peninsula)	63	95.2	4.8
8/1	Coal Bay (Alaska Peninsula)	66	72.7	27.3
8/13	Hook Bay (Alaska Peninsula)	47	80.9	19.1
7/10	Unalakleet (Northwestern Alaska)	60	86.7	13.3
High seas samples				
7/26	53°55N. 159°40W.	50	96.0	4.0
7/25	53°00N. 160°00W.	38	94.7	5.3
7/5	51°00N. 169°56W.	52	15.4	84.6
7/4	52°00N. 169°53W.	43	20.9	79.1
7/2	53°58N. 170°01W.	23	8.7	91.3
7/3	53°18N. 170°00W.	54	9.3	90.7
6/27	59°00N. 170°00W.	42	59.5	40.5
6/21	52°59N. 175°00W.	64	10.9	89.1
6/24	56°00N. 176°00W.	69	15.9	84.1
6/23	55°00N. 176°00W.	53	9.4	90.6
6/22	54°00N. 176°00W.	49	18.4	81.6
6/15	51°31N. 176°25W.	41	14.6	85.4
7/27	51°31N. 176°42W.	26	65.4	34.6
6/14	51°23N. 176°45W.	32	9.4	90.6
6/22	52°38N. 178°47W.	40	12.5	87.5
6/30	60°00N. 180°	64	12.5	87.5
6/28	58°00N. 180°	60	15.0	85.0
6/27	57°00N. 180°	44	38.6	61.4
6/26	56°00N. 180°	20	10.0	90.0
6/25	55°00N. 180°	63	14.3	85.7
6/24	54°00N. 180°	86	16.3	83.7
6/13	53°30N. 180°	23	0.0	100.0
6/23	52°59N. 179°55E.	48	14.6	85.4
7/4	58°00N. 175°00E.	70	20.0	80.0
5/25	48°00N. 175°00E.	45	22.2	77.8
7/15	55°00N. 175°00E.	84	13.1	86.9
7/5	56°49N. 173°22E.	52	13.5	86.5
5/26	48°57N. 169°29E.	23	17.4	82.6
7/15	48°48N. 168°36E.	22	18.2	81.8
7/5	52°32N. 163°48E.	34	8.8	91.2
6/15	48°31N. 162°31E.	23	17.4	82.6
5/30	44°54N. 161°03E.	22	4.5	95.5
7/10	47°20N. 155°53E.	53	22.6	77.4
6/30	45°24N. 152°58E.	33	33.3	66.7
6/14	43°48N. 150°27E.	42	28.6	71.4

ndividual fish from the inshore and high seas ples were classified into either of the two con- ntal groups. Sample locations and results of sification are found in Table 15. All North erican inshore samples were correctly classified their continental group. Samples from the ska Peninsula and Northwestern Alaska were nd to be distinguishable from the Asian standard. ividuals in the high seas samples were most quently classified as Asian. However, three sam- s obtained on the North Pacific in the latter part July were predominantly of North American type (Figure 30). One other sample obtained from eastern Bering Sea on June 27 was classified as efly North American.



155°
160°
165°
170°
175°
180°
175°
170°
165°
160°
155°
60°
50°
40°
▲ PREDOMINANTLY NORTH AMERICAN TYPE FISH
● PREDOMINANTLY ASIAN TYPE FISH

IGURE 30. Classification of 1959 high seas samples of pink salmon into continental groups.

Summary and Conclusions

Morphological and scale differences between fish are being examined as a possible method of separating Asian from North American pink salmon in high seas samples. A preliminary study with the 1957 collections indicated additional characters were needed to distinguish fish of the Alaska Peninsula, Aleutian Islands and Northwestern Alaska from those of Asia. As a result, four new characters were added to the separation analysis after appropriate testing. The new characters were used with two from the previous study to classify the 1959 collections to continent of origin. In the 1959 collections, all North American inshore samples were distinguishable from Asian samples. However, only four high seas samples resembled North American type fish. The majority of samples were classified as Asian.

Reference

Amos, Murray H., Raymond E. Anas and Roger E. Pearson. 1960. Use of a discriminant function in the morphological separation of Asian and North American races of pink salmon, *Oncorhynchus gorbuscha* (Walbaum). U.S. Bureau of Commercial Fisheries, Biological Laboratory, Seattle, Washington, October 12, 1960. 55 pp. Processed. (INPFC Doc. 412.)

CHUM SALMON STUDIES

by John LaLanne

The principal objective of this study has been to entify the continental origin of chum salmon taken sea. A large number of chum salmon mor- iological characters (structures and body form) ive been examined for possible consistent differences tween Asian and North American chum salmon. he most useful characters have been the number of rtebral segments, the number of fin ray elements, d other segmented bony structures which have own differences between populations of Asian and orth American chum salmon.

We have applied these characters in a method ich enables us to identify the continental origin chums taken at sea with the exception of those m rivers entering the Bering Sea, and rivers of the odiak Island region. Because these rivers most ely contribute significant numbers of chums to the high seas area under study, we have begun examination of scale structures for possible differences between chums from these regions.

Chum salmon scales are flat calcified structures, generally round or oval in shape. Near the center is a platelet or focus. Circular or semicircular ridges (circuli) concentric to the focus occur on the anterior portion of the scale (Fig. 31). When scale growth is rapid, thick widely spaced circuli are formed; when growth is slow, narrow closely spaced circuli are formed. Since protracted slow growth usually occurs once annually in the winter, the band of narrow closely spaced circuli formed is called an annulus and is used in determining the age of the fish. Counts of the number of circuli and scale length measurements are the scale characters most commonly used to identify the origin of the fish.

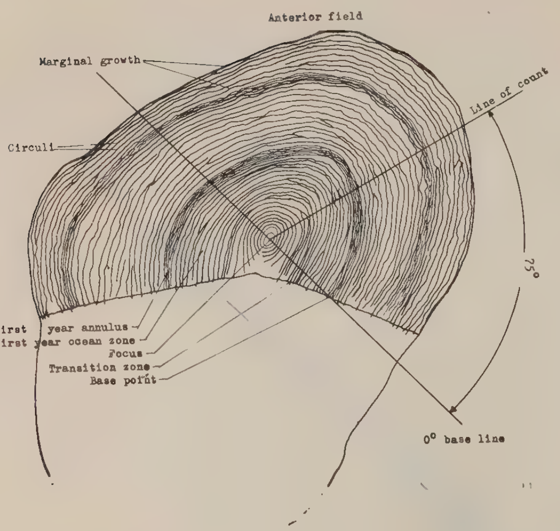


FIGURE 31. Diagram of chum salmon canted right scale with descriptive notations.

As a prerequisite to using scale characters for differentiating Asian and North American chums, it is necessary to evaluate the effect on the characters of such extraneous factors as differences in scale shape, the location on the fish's body from which scales are sampled, the area studied on the scale, the sex or age of the fish, and others. It is possible that supposed differences between chums from the two continents could be due only to these factors.

For example, if the number of circuli is different for scales sampled near the head of the fish and those sampled near the tail, then all scales must be taken from one or the other location. Otherwise, differences in number of circuli between Asian and North American chums would occur simply because North American chum scales were sampled, say, near the head and Asian scales near the tail.

Also, it is important to know the age of the fish so that the different age groups can be compared. The annual marks on scales have been used to determine the age of many species of fishes. Only limited study has been made of the scale method of age determination of chum salmon.

In 1961, chum salmon morphological research was directed toward evaluating the effect of extrane factors on scale characteristics, developing meth of producing consistent and comparable scale da and examining the validity of using scales for a determination.

EFFECT OF EXTRANEOUS FACTORS ON SCALE CHARACTERISTICS

Scale shape. It was found that with the excepti of a few randomly distributed intermediate ty scales, the scales on a chum salmon are of two gene shapes, canted left and canted right (Fig. 31). T spacing and number of circuli change with sc shape. If a fixed line of count or measurement w established for all scales then a spurious differe between Asian and North American chums cou result from more canted left scales being sampl from Asian chums than North American chur Therefore scale shape must be considered wh counting circuli or measuring scale lengths. T line of count or measurement should change with t scale shape.

Line of count and measurement. In an attempt obtain consistent results, chum salmon scale cou and measurements have usually been made along within certain limits on either side of the long axis of the scale. The longest axis is generally tablished as the longest radius from the center of t focus to the periphery of the anterior portion of scale or the edge of a particular annulus.

A comparison was made between the longest a method of establishing the line of count and ot methods. A base line on the scale from which line of count can be projected was found to prov a more consistent line of count than the longest a method (Table 16). The base line is defined a line from the center of the focus to a base point wh the first annulus enters the transition zone betw the anterior and posterior portions of the scale (F 31). There are two base points, one where annulus enters the transition zone on the left and on the right. The base point closest to the focus used. The use of the closest base point accounts scale shape. The closest base point is on the right canted right scales and on the left for canted left sca

TABLE 16. Comparison of angular variation within line of count by " base line " and " longest axis " methods. For each scale two determinations were made by each method.

Method	N	Min. diff. (degrees)	Max. diff. (degrees)	$S\ D$	Mean diff.
Base line	22	0.0	8.5	1.95	1.4
Longest axis	22	0.0	37.5	9.50	5.0

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pp. 292–295

Redescription and Second Known Record of the Bothid Fish, *Monolene asaedai* Clark

Herbert C. Perkins

Redescription and Second Known Record of the Bothid Fish, *Monolene asaedai* Clark

HERBERT C. PERKINS

IN AUGUST 1961, a series of 21 specimens of the bothid genus *Monolene* was taken by bottom trawling from the research vessel *Black Douglas* (Cruise 6108-B) with an otter trawl in 51–53 fathoms, north of the Tres Marias Islands (22°22′N, 106°14′W) off the Pacific coast of Mexico.

Examination of these fish showed that they were apparently *Monolene asaedai*, first described by Dr. H. Walton Clark in 1936 from four specimens: three from Port Angeles Light, Oaxaca, Mexico; and one from 18°14′N, 103°23′W, in 60 fathoms (near Punta San Telmo, Michoacan, Mexico).

The new specimens agreed in general with Clark's description except in the number of gill rakers on the first arch. He gave 3 + 5 as the count for the first arch of the holotype (California Academy of Sciences 4729). The new specimens have a range of 5 or 6 + 8 to 10 rakers on the first arch. Subsequent examination of the holotype and paratypes (CAS 4729, 4727, 4728, and 4805) revealed that they possess 6 + 9, 5 + 9, 6 + 9, and 5 + 9 gill rakers, respectively, on the first arch.

This second record of *Monolene asaedai* represents a northward range extension of about 250 miles. This species is redescribed on the basis of the 25 known specimens and is illustrated for the first time (Fig. 1). Body proportions, meristics, and collection dispositions are given in Table 1; body proportions showed essentially no change in value with increase in standard length within the size range of available specimens. Specimens are deposited in the collections of the California Academy of Sciences (CAS), the U. S. National Museum (USNM), the University of California at Los Angeles (UCLA), Scripps Institution of Oceanography (SIO), and the U. S. Bureau of Commercial Fisheries Biological Laboratory, La Jolla, California (BLLJ).

Monolene asaedai Clark

Monolene asaedae Clark, 1936, Proc. Calif. Acad. Sciences, 21 (29) :285. (Pacific coast of Mexico, Templeton Crocker Expedition of 1932; named for the expedition artist, Mr. Toshio Asaeda; the specific name is emended to *asaedai* according to Articles 31 and 32 (c) o the International Code of Zoologica Nomenclature, 1961.)

Depth of body.—39 to 44% standard leng (standard length, S.L., measured from of snout to end of hypural plate, dep measured at its greatest vertical dimensio

Head length.—25 to 31% S.L. (head me ured from tip of snout to anterior edge cleithrum), an indentation or notch in t profile just above the position of the nost of the eyed side is absent or slight in so specimens and fairly pronounced in othe this may be due to intraspecific variation more probably a condition of preservati

Snout.—Shorter than eye, half or sligh more than half the length of the eye.

Eye diameter.—7.0 to 8.2% S.L., 3.3 to into head (the lower eye, not the orl measured in a direction parallel to the bc length).

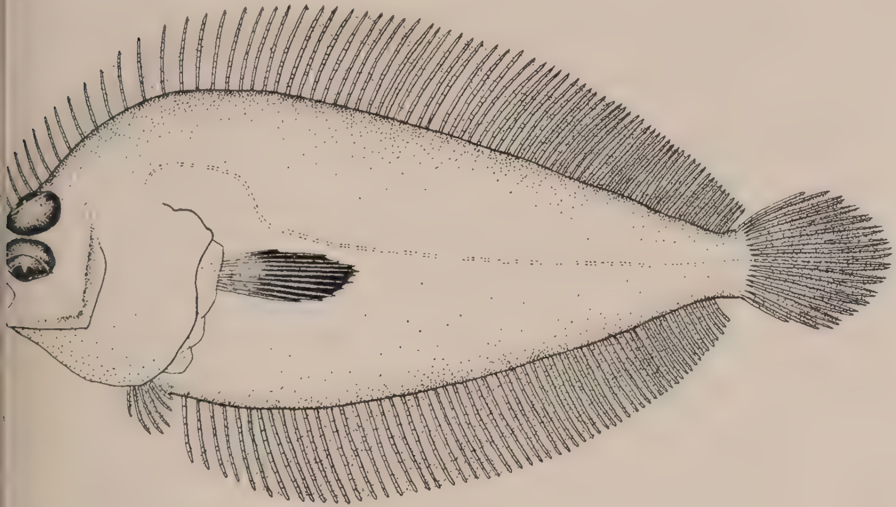
Interorbital width.—Narrow, ridged, mm in the largest specimen of 86 mm sta ard length, 1 mm or less in specimens fr 70–80 mm standard length.

Upper jaw.—7.9 to 9.2% S.L., 2.8 to into head, extending to the anterior half the lower eye.

Lower jaw.—10.3 to 12.0% S.L., 2.2 to into head.

Gill rakers.—5 or 6 + 8 to 10 on the f arch; short and slender; the base of the f three or four rakers on the anterior end the lower limb twisted onto the limb so t they lie laterally along it (it is proba that due to the unusual position of th rakers they were missed in the original amination of the species). Gill raker cou for all four gill arches of a typical specim 6 + 9 on the first arch, 1 + 9 on the seco 2 + 9 on the third, and 8 or 9 on fourth arch. The first three arches have rakers on their medial side, however, th are 5 or 6 well-defined rakers on the me side of the fourth arch.

Scales.—61 to 74 along the lateral (counted from the upper angle of the opening to the lateral line, then along i



ig. 1. *Monolene asaedai,* 79 mm S.L., north of the Tres Marias Islands (22°22′N, 106°14′W) the Pacific coast of Mexico, 25 August 1961, USNM.

end of the hypural plate); cycloid on h sides of the body, deciduous on the d side. On the blind side the scales are quently pigmented on the anterior third the head and along the anterior third of body margins.

)orsal fin.—76 to 85 rays; the first two rays newhat remote from the others, occurring the blind side just behind the nostril and line with its upper edge; the third and litional rays occurring on the body ridge; ne of the rays prolonged, longest rays in middle of the fin.

nal fin.—58 to 66 rays; none of the rays longed, longest rays in the middle of fin.

Pectoral fin.—9 to 12 rays, usually 11, on ocular side; none of the rays prolonged, gth two or less into head (most of the ecimens have damaged pectorals). On the ed side the pectoral arch has a well-devel- ed hypercoracoid or scapula; the hypo- racoid is broad immediately below the pula tapering ventrad in a long slender rve; the lower actinost is not connected the scapula by bone; a long, slender, post- ithrum is present. On the blind side here there is no pectoral fin (typical of adults of this genus), there are several nute bones that may be actinosts or rudi- ntary coracoid bones, and a weak, slender, st-cleithrum is present.

Pelvic fins.—6 rays; none prolonged; both fins of equal length, that on the eyed side on the body ridge, originating slightly in advance of the blind side fin. The sharp "spine" protruding between the pelvic fin bases is actually a ventroposteriad spur-like projection of the pelvic bone.

Caudal rays.—16 to 18 [16 (1), 17 (22), 18 (2)], with a normal complement of 17 caudal rays, 13 branched; in the upper lobe there are 4 rays associated with the upper bone (a fusion of an epural and a hypural) and 5 rays with the adjacent hypural; in the lower lobe there are 4 rays associated with each hypural. In the specimen with 16 caudal rays there are 4 rays associated with each of these bones. One of the specimens with 18 caudal rays had 4 + 5 rays both dorsally and ventrally; the other specimen had 5 + 5 dorsally and 4 + 4 ventrally.

Vertebrae.—Total 38–40 [38 (4), 39 (10), 40 (1)]; a breakdown distinguishing abdominal and caudal vertebrae is: 10 + 28 (4), 10 + 29 (8), 11 + 28 (2), and 10 + 30 (1). The anteriormost vertebra bears a reduced neural spine, markedly shorter than that which arises from the immediately adjacent vertebra.

Teeth.—Short, slender, and sharp; in an irregular band on both jaws; on eyed side, lower jaw teeth posteriorly shorter and fewer; on blind side, lower jaw teeth poste-

Table 1. Body Proportions in Percentage of Standard Length and in Ratios, Meristics, and Collection Dispositions of the Known Specimens of *Monolene asaedai*

Standard Length (mm)	Body Proportions					Body Proportions (Ratios)					Meristics							Collection
															Gill Rakers		Scales	
	Body Depth	Head	Upper Jaw	Lower Jaw	Eye	Depth in S.L.	Head in S.L.	Upper Jaw in Head	Lower Jaw in Head	Eye in Head	Dorsal Rays	Anal Rays	Pectoral Rays	Caudal Rays	Upper Limb	Lower Limb	Lateral Line	
53	38.9	25.5	9.2	11.3	7.0	2.6	3.9	2.8	2.2	3.6	80	61	11	18	5	9	68	CAS 4805*
57	42.1	29.8	8.8	11.4	7.9	2.4	3.4	3.4	2.6	3.8	81	64	11	17	6	8	74	SIO 62–77
66	43.1	28.8	8.3	10.9	8.2	2.3	3.5	3.5	2.6	3.5	76	61	11	17	6	9	61	"
67	43.7	28.4	8.2	10.9	7.2	2.3	3.5	3.5	2.6	4.0	83	64	—	17	6	10	67	"
68	39.7	25.0	8.5	10.4	7.5	2.5	4.0	2.9	2.4	3.3	78	63	11	17	6	9	66	CAS 4729**
69	39.6	26.8	8.3	10.6	7.8	2.5	3.7	3.2	2.5	3.4	83	60	12	16	6	9	67	CAS 4728*
70	41.0	28.6	8.1	10.3	7.7	2.4	3.5	3.5	2.8	3.7	81	62	11	17	6	10	68	SIO 62–77
70	41.9	29.3	8.4	10.9	7.7	2.4	3.4	3.5	2.7	3.8	80	59	11	17	6	9	70	CAS 20443
72	41.9	28.9	8.2	10.6	7.5	2.4	3.5	3.5	2.7	3.9	76	59	11	17	6	8	72	SIO 62–77
73	42.0	28.8	8.5	10.4	7.3	2.4	3.5	3.4	2.8	4.0	79	59	11	17	6	8	68	"
73	41.1	29.5	8.2	10.7	7.0	2.4	3.4	3.4	2.8	4.2	83	63	11	17	6	9	68	"
73	41.0	28.8	8.4	10.5	7.1	2.4	3.5	3.4	2.8	4.0	76	58	10	17	6	8	68	"
73	(Specimen cleared and stained)										85	62	11	17	6	8	—	BLLJ B6108–77
74	41.2	29.7	8.2	10.5	7.6	2.4	3.4	3.6	2.8	3.9	79	62	11	17	6	10	72	SIO 62–77
74	43.1	30.8	9.6	12.0	8.1	2.3	3.2	3.2	2.6	4.2	80	58	11	17	5	9	70	CAS 4727*
75	40.4	27.2	7.9	11.4	7.9	2.5	3.7	3.5	2.8	3.7	81	64	11	17	6	8	74	USNM ——
76	41.2	28.3	7.9	10.3	7.5	2.4	3.5	3.6	2.8	3.8	76	59	11	17	6	8	72	SIO 62–77
76	38.9	25.0	8.2	10.4	8.1	2.6	4.0	3.1	2.4	3.8	77	59	11	17	6	10	67	"
79	43.0	27.2	8.2	10.3	7.3	2.3	3.7	3.3	2.7	3.7	79	63	9	18	6	8	65	CAS 20443
79	41.5	28.5	8.2	10.8	8.1	2.4	3.5	3.5	2.6	3.5	78	59	11	17	5	8	73	USNM ——
80	40.6	28.1	8.4	10.6	7.5	2.5	3.6	3.4	2.6	3.8	82	65	11	17	5	10	70	UCLA W62–55
82	39.4	28.7	8.4	10.8	7.4	2.5	3.5	3.4	2.6	3.9	84	66	12	17	6	8	67	BLLJ B6108–77
83	(Specimen cleared and stained)										79	61	11	17	6	10	—	"
85	40.8	28.2	8.2	10.6	7.6	2.4	3.5	3.4	2.7	3.7	80	62	11	17	6	10	69	CAS 20443
86	41.5	28.1	9.0	10.4	8.1	2.4	3.6	3.1	2.7	3.5	77	59	10	17	6	10	67	UCLA W62–55

* Paratypes.

only slightly shorter, more numerous on eyed side. Upper jaw teeth on side present only on the anterior third e premaxillary, upper jaw teeth on side present along the entire length e premaxillary, except where it overlies lower jaw, larger anteriorly. No teeth omer or palatines.

lor.—Dark brown, no pattern discernible use of the loss of many scales on the side, fins dark brown, the posterior half e pectoral fin nearly black.

oods (1961) has distinguished the At- c species of *Monolene*. There are three ies in the eastern Pacific in addition *M. asaedai*: *M. maculipinna* Garmen off Panama and Colombia in 112–210 oms with D. 98–102, A. 78–85, lateral- scales ca. 104–108, eye diameter 6.3– S.L., and depth of body ca. 30–35% *M. danae* Brunn from the Gulf of ama in the upper 400 meters over 3,140 ers depth with D. 103, A. 80, lateral- scales about 112, and with smaller eye % S.L.) and deeper body (37.6% S.L.) in *M. maculipinna*. *M. dubiosa* Garmen from about 8 miles southwest of Acapulco, Mexico in 141 fathoms with D. ca. 83, A. 58, lateral-line scales 72 (scale count of 83 originally reported), and with a smaller eye (5.6% S.L.) and deeper body (45.8% S.L.) than in *M. asaedai*. I am grateful to Dr. Giles W. Mead for the opportunity to examine the holotype of *M. dubiosa* (Museum of Comparative Zoology No. 28538).

I would like to express my appreciation and thanks to W. I. Follett and Lillian Dempster of the California Academy of Sciences for allowing me to examine the holotype and paratypes, also to George Mattson of the U. S. Bureau of Commercial Fisheries, La Jolla, for his drawing of the species.

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U. S. BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY, LA JOLLA, CALIFORNIA.

EXTRAIT

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1963
North Atlantic [illegible]
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44.

Tagging as a Technique in Population Studies of the Sea Scallop

By
J. A. POSGAY*

Introduction

The tagging experiments described here were originally designed to provide data on growth rates and identification of stocks. Later in the investigation it became important to know something of mortality rates, and the accumulated tag return data were analyzed for this purpose.

Methods

It is extremely simple to tag a sea scallop. There is a deep byssal notch in one ear of the lower valve which is not present in the upper valve. A touch causes the scallop to withdraw the mantle and a fine hole is drilled in the ear of the upper valve just over the byssal notch. A stainless steel pin bearing a numbered Petersen disc is pushed through the hole and bent over to hold it in place.

The disturbance of being fished up, handled, and tagged causes the scallop to lay down a check mark on the shell, permanently defining its size when tagged. In addition, so that there will be no uncertainty about locating the tagging check on recaptured animals, the margin of the shell is nicked with a triangular file. This eliminates the necessity of measuring and recording the size of the tagged scallops before they are released.

Recovery Methods

Since all sea scallops are shucked at sea — the shells and viscera are discarded at the time — and only the adductor muscles ("eyes" or "meats") landed, recovery depends upon alerting the fishermen to watch for the tagged animals. Since over 70 percent of United States sea scallop catches are landed at New Bedford, Massachusetts, and sold through a single auction room, our publicity effort is concentrated there. A Bureau of Commercial Fisheries agent interviews each skipper in the auction room for data on the location he fished and days spent on the grounds. The agents are encouraged to ask about tags and generally keep the fishermen aware of this as well as other tagging programs. In addition, they have a cash fund from which they pay the one dollar reward on the spot. Other agents in other ports have similar instructions and funds. Posters are put up in places where fishermen congregate and there are occasion articles in newspapers and magazines. Under a recip rocal arrangement, our tags are returned and pai for by agents of the Fisheries Research Board (Canada in their ports from their fishermen.

All reported tagged shells are forwarded to th laboratory in Woods Hole together with the locatio and date of recapture, name of the person to whor the reward was paid, and the boat. The vital sta tistics of the tagged shell are entered on a file car and a form letter of appreciation is sent to whoeve reported the tagged shell. This letter includes infor mation on the date and location of release on th tags which were reported.

Early Releases

In December 1955 we tagged and released 82 sea scallops at three locations on Georges Banl Another 2100 were released at 11 locations in Ju 1956 (Figure 1). Returns from these experimen were disappointingly low (Table 1). Some of th tagged scallops had been released in areas wher there was little fishing during the first year afte release, but other areas should have been heavil fished. We suspected that many of our tagged anima were being caught and shucked but that the tag were not noticed. Apparently, since the upper valv is held down in the palm of the left hand durin the shucking operation, few fishermen saw the ta

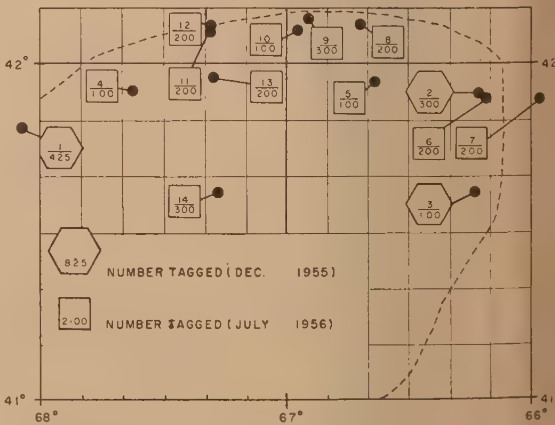

Figure 1. Locations of tagged sea scallops released in 1955 an 1956. The upper number is the number of the drop; the lowe the number released.

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* U.S. Department of the Interior, Fish and Wildlife Service, Bureau of Commercial Fisheries Biological Laboratory, Woods Hole, Massachusetts, U.S.A.

gh some had reported seeing the tag on the while it was in the air after they had tossed it ard. Shucking scallops is a monotonous task n experienced scalloper does it automatically, ut looking, so it seems likely that many more animals were recaptured than were reported.

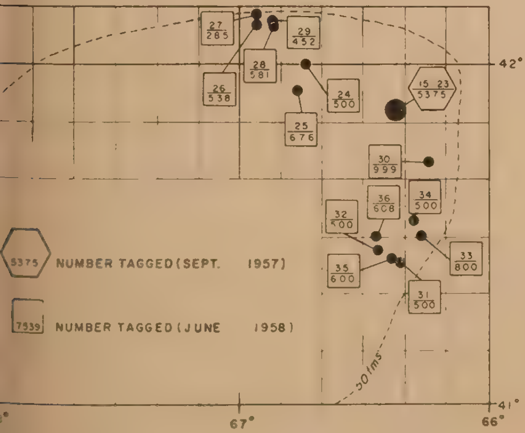
Table 1

returns from the 1955 and 1956 experiments

Date	No. tagged	Number returned				
		Year 1	Year 2	Year 3	Year 4	Year 5
12 Dec 1955	425	0	0	0	0	0
13 Dec 1955	300	12	3	0	3	0
17 Dec 1955	100	0	0	0	0	0
6 July 1956	100	0	0	0	0	0
6 July 1956	100	0	0	0	0	0
7 July 1956	200	0	0	0	0	0
7 July 1956	200	0	0	0	0	0
7 July 1956	200	0	1	0	0	0
7 July 1956	300	3	4	0	0	2
8 July 1956	100	10	3	0	0	
8 July 1956	200	0	0	0	0	
8 July 1956	200	29	0	0	0	
8 July 1956	200	20	0	0	0	
8 July 1956	300	0	0	0	0	
Total	2925	74	11	0	3	2

Later Releases

e decided to increase the visibility of the tag by ng a yellow plastic streamer to the disc, and also crease the possiblity of recovering a good number e tags by releasing them in a restricted area. thus tagged and released 5375 animals in September 1957 (Figure 2). In the first six months at large, (14 percent) were reported. Encouraged by these lts we tagged and released another 7539 at 13 tions (Figure 2) in June 1958. The returns from drops have been very good (Table 2).



re 2. Location of tagged sea scallops released in 1957 and . The upper number is the number of the drop; the lower, the number released.

Table 2

Tag returns from the 1957 and 1958 experiments

Drop no.	Date	No. tagged	Number returned		
			Year 1	Year 2	Year 3
15	22 Sept 1957	294	11	0	0
16	22 Sept 1957	498	59	119	30
17	22 Sept 1957	589	0	3	0
18	22 Sept 1957	297	31	4	0
19	23 Sept 1957	495	103	67	2
20	23 Sept 1957	575	200	84	6
21	23 Sept 1957	790	230	99	22
22	23 Sept 1957	355	5	4	0
23	23 Sept 1957	1482	351	225	21
24	23 June 1958	500	0	0	
25	23 June 1958	676	85	46	
26	22 June 1958	538	119	61	
27	23 June 1958	285	0	0	
28	23 June 1958	581	55	4	
29	23 June 1958	452	60	2	
30	21 June 1958	999	318	61	
31	23 June 1958	500	42	0	
32	24 June 1958	500	42	0	
33	24 June 1958	800	206	1	
34	24 June 1958	500	62	1	
35	25 June 1958	600	160	0	
36	25 June 1958	608	3	8	
	Total	12914	2142	789	

Movement

The sea scallop is a vigorous swimmer and there have been persistent reports of beds moving away, to the distress of the fishermen. There have also been reports, at least one of which I know to be reliable, of large numbers of small scallops being seen at the surface in water as deep as 25 fathoms.

Table 3 gives a summary of the reported locations of capture of 2191 tagged sea scallops on which we had complete recovery data. Over a period of $2^1/_2$ years, 80.4 percent were reported within 2 miles of the release location, 97.1 percent within 10 miles. A small tendency for dispersal to increase with time is apparent. This may be the result of the disturbance caused by dredging. It must be stressed that some of the reported locations of capture may be considerably in error.

Table 3

Distance of reported location of recapture from location of release for 2191 tagged sea scallops (by half-yearly periods)

Half-year periods	Less than 2 miles %	2—10 miles %	Over 10 miles %	Total number
1	84.3	12.0	3.7	1115
2	84.2	13.9	1.9	374
3	83.9	14.5	1.6	380
4	51.7	45.3	3.0	232
5	75.6	21.1	3.3	90
Total	80.4	16.7	2.9	2191

From these results, it seems that we are reasonably safe in concluding that the movements of individual sea scallops are not large and that aggregations do not move about but may become dispersed somewhat. All of these scallops were larger than 75 mm in length; smaller scallops have fragile shells which usually break if an attempt is made to tag them. Large-scale movement of smaller scallops still remains a possibility. It is also possible, but I believe unlikely, that the tag inhibits movement.

Growth

The large number of returns from the 1957 and 1958 tagging experiments provided very satisfactory data for calculating growth rates; but, since the important grounds were widely separated, we felt that different areas would have different growth patterns. Tagging all over Georges Bank would be a tedious and expensive operation, so we made a vigorous attempt to master the technique of locating annual rings on the shell as had been done by Stevenson and Dickie (1954) working with sea scallops from the area off Digby, Nova Scotia.

After we had developed a satisfactory technique for locating what we considered to be annual rings, we were faced with the need to validate our results. For this purpose we used a sample of 392 tagged shells which had been returned after being at large for about a year. The Walford regression for this sample, calculated from the increment added between release and return was $L_{t+1} = 47.3 + 0.662\ L_t$. The annual rings on a sample of 411 shells from the same location gave us $L_{t+1} = 42.4 + 0.706\ L_t$. To avoid subjective bias, the different methods were used by different investigators. The two equations give almost the same results when used to determine the growth of scallops from an arbitrary length of 85 mm onwards.

	L_t	L_{t+1}	L_{t+2}	L_{t+3}	L_{t+4}	L_{t+5}	
Tags	85.0	103.6	115.9	124.0	129.4	133.0	mm.
Rings	85.0	102.4	114.7	123.4	129.5	133.8	mm.

From our tag recoveries we have been able to estimate the time of year when the annual ring is laid down, by assuming that the equable temperature regime of Georges Bank causes only a slight difference in the seasonal growth rate and that the tagging check ring is the effect of only a short time inhibition of growth. If these assumptions are true, the position of the annual ring between the tagging check ring and the margin shows that it was formed in late spring, between April 1 and June 1. This suggests that the
annual ring is the result of minimum water tem
tures.

Tagging Mortality

Mortality due to tagging in these experimer
in our opinion, low. The animal is not wound
the tag or pin and scallops returned shortly
tagging have already sealed off the hole and
part of the pin in contact with the mantle,
new shell. The coincidence of the growth ra
tagged and untagged scallops also suggests
tagging mortality. There is a possibility that impr
ly applied tags may get between the valves of
few individuals and cause some mortality soon
tagging. We receive some tagged shells, out for
time, which show no growth and we assume
means that the animal died soon after it was ta

Calculation of Mortality Rates

Unlike fin fish, a tagged sea scallop which
from any cause but is not recovered is not removed
the tagged population. The valve, with tag atta
persists for some time, perhaps 2 or 3 years.
of our recovered shells have fouling organism
their inner surface and were certainly dead
recaptured. Others still have part of the add
muscle attached and were certainly alive.
remain, however, quite a few returns which we c
identify certainly as being alive or dead when r
tured. Because dead animals do not leave the po
tion and all cannot be identified among those rec
ed, any mortality rate calculated from the ra
return of tagged shells can be regarded as a fi
mortality rate.

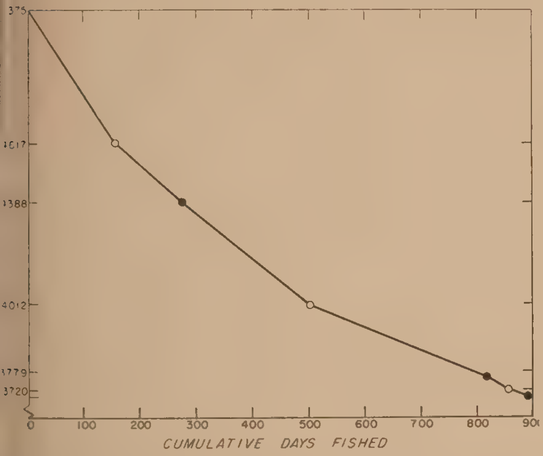
There are other complications in the ana
The tagged individuals do not distribute themsel
random through the total population, nor is fi
conducted at random. The number of tagged
reported is certainly less than the number recapt
while the amount of effort reported for the tr
which they were caught is larger than that
was expended on the tagged animals. The ta
scallops occupy only a limited amount of the
over which the boats range in fishing them

Accepting these limitations and complica
the iterative analysis of Beverton and Holt (
p. 192) was applied to the data of Table 4. The
tions would not converge. A simple analysis, pl
the logarithm of the numbers remaining against th
of the effort required to effect the reduction i
manner of a survival curve, was then atter
(Figure 3). The sharp decrease in slope after th
six months and again after the eighteenth
suggests that quite a few tags either fall off the
or are being recaptured but not reported.

Table 4

ber of tagged sea scallops returned from drops 23, and the reported effort required to catch them, summed by half-yearly periods

Period	1	2	3	4	5	6
ecaptured	758	229	376	233	59	23
fished	158	108	237	317	34	36
captured	14.1	5.0	8.6	5.8	1.6	0.6
ulative ys fished	158	266	503	820	854	890
ber remaining .	4617	4388	4012	3779	3720	3697
nos. remaining	8.439	8.388	8.299	8.239	8.223	8.217



ure 3. Apparent survival curve of the sea scallops tagged in tember 1957, plotted at 6 month intervals as a function of the reported effort in the area of release.

With all the bias in the data, it does not seem to be worthwhile to try a more sophisticated analysis. During the first six months after the tagged sea scallops were released, 158 days of fishing spread over the area in which the tags were located (about 15 square miles) resulted in the return of 14.1 percent of the tags. This gives us a minimum figure for the fishing mortality generated by this effort over this area. It is impossible to say from these data by how much this figure must be multiplied to arrive at the true fishing mortality. For this purpose, it will be necessary to conduct a specifically designed experiment.

Summary

The release of 2925 sea scallops tagged with a single Petersen disc led to the return of only 90 after 5 years at large. The addition of a 6-inch length of yellow plastic tape on 12914 tagged scallops led to the return of 2931 during 2 years at large.

The returned shells show that the beds move little if at all. They have been used to estimate growth rates, validate the technique of locating annual rings, and deduce the season of ring formation.

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Schmidt & Klaunig, Kiel

Reprinted from
Proceedings of the
GULF AND CARIBBEAN FISHERIES INSTITUTE
Fifteen Annual Session, November, 1962
Pages 110-115

Progress on Blue Crab Research in the South Atlantic

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Abstract

Research on blue crab in the South Atlantic was initiated by the Bureau of Commercial Fisheries on a limited scale in 1957. It was not until 1961, however, that money was appropriated specifically for a blue crab program. Prior to the initiation of this study very little was known concerning life history, migration, distribution, racial identity, abundance, recruitment, and general biology of the species in the South Atlantic area.

Population studies in the Neuse River, North Carolina, have investigated methods for estimating the size of crab populations. Tagging of adult crabs in the Newport River, North Carolina, in three estuaries in South Carolina, in the St. Johns River, Florida, and at various coastal locations in North Carolina, South Carolina, and Florida, is providing valuable information on the movements of blue crabs. Present indications are that there is very little migration between estuaries, and the blue crab fishery in a particular estuarine system cannot depend on recruitment from other geographical areas.

Studies of blue crab larvae are being conducted both in the laboratory and n the field. Analysis of plankton collections taken in estuaries and offshore from Florida to North Carolina provides evidence that development through the early ife stages may take place at considerable distances offshore. Blue crab larvae have been successfully hatched and reared in the laboratory under various conditions of salinity and temperature. Mortality of the zoeal stages does not appear o be directly associated with either salinity or temperature. Recent work has established that mortality and rate of development of the megalops, that stage ust prior to the first crab, are considerably affected by temperature and salinity.

e Blue Crab Fishery

E BLUE CRAB FISHERY is one of the most valuable fisheries in the United tes. It is extensive in terms of landings, number of fishermen, and area fished. om its beginnings in the Chesapeake Bay area more than 80 years ago, it has anded southward along the Atlantic Coast to Miami, Florida, and along the Gulf Coast from Florida to Texas. Landings of blue crabs in the United States in 1960 totaled more than 150 million pounds, valued at 9 million dollars. This catch represented the efforts of some 10,000 fishermen and provided employment for many other persons in processing plants and allied industries.

In the southeastern Atlantic states, more than 40 million pounds of blue crabs were landed in 1961. This poundage was more than for any other food fish species, and was exceeded in value by food species only by shrimp.

When we speculate on the future of this valuable resource, it is alarming to find that our knowledge of the species is not commensurate with our estimate of its economic importance and is not sufficient to answer questions now of major concern to the industry. Scientific knowledge on which to base effective management practices, or which would permit predicting fluctuations in abundance, is lacking.

Development of the Blue Crab Program

The lack of knowledge concerning the resource prompted the blue crab industry, working through the Atlantic States Marine Fisheries Commission, to request the Bureau of Commercial Fisheries to undertake scientific studies on the biology of the blue crab. The basic problem of the proposed research program was the determining of factors affecting the abundance of marketable crabs.

One of the factors affecting the abundance of a species is the survival rate of the early stages of life, and variation in survival rate often is a major cause of fishery-independent fluctuation in exploited fish populations. Accordingly, the Blue Crab Program began with a study of the early stages in the life cycle and, in 1957, a contract was awarded to the Oyster Institute of North America for this purpose. In 1959, this contract was transferred to Duke University, and work on larval forms has continued at the Duke Marine Laboratory until the present time.

With the curtailment of the Shad Program, some funds and personnel were made available for blue crab research. In 1958 and 1959, a study was conducted of the movements of blue crabs in the coastal waters of South Carolina. This was a cooperative study between the Bureau of Commercial Fisheries Biologica Laboratory, Beaufort, North Carolina, and the Bears Bluff Laboratories, Wadmalaw Island, South Carolina. The objective of this project was to determine if commercial-size crabs migrate from one estuarine system to another, or i the crabbing industry in a particular estuary is independent of the migratory movements of crabs.

A total of 4,353 blue crabs of 5 inches or greater carapace width were tagged and released in 3 estuaries and at 2 coastal locations in South Carolina Locations of 530 returns indicated that most of the crabs did not migrate between estuaries, but limited their movement beween the lower estuary and adjacent coastal waters. Only 3% of the tagged crabs recaptured were recovered in estuaries other than those in which tagged. This indicated, a least for South Carolina waters, that the blue crab fishery in a particula estuary could not depend upon recruitment of marketable size crabs from othe geographical areas. It also indicated that management measures might b confined to individual estuarine systems rather than large coastal region (Fischler and Walburg, 1962).

In 1961, Bureau funds were made available specifically for a Blue Cra Program. Studies were begun in the Newport River and adjacent sounds i orth Carolina, and in the St. Johns River, Florida. Operations in North arolina are conducted from the laboratory at Beaufort; the St. Johns work, om a field laboratory established at Green Cove Springs, Florida.

Prior to the initiation of the Blue Crab Program, almost no information was 'ailable on migration, distribution, racial identity, abundance, recruitment, ıd general biology of the species in the southeastern Atlantic states. Suggested asons for this lack of information have been: (1) studies are made difficult ecause the fishery is pursued by many small operators working over a very rge geographical area, and (2) the life history of the species is complicated ıd only recently have some phases been described.

istribution of Callinectes Species

Four species of the genus *Callinectes* are known to occur in the coastal aters of the southeastern Atlantic states. These are *C. sapidus, C. ornatus,* . *danae*, and *C. marginatus*. Generally speaking, only the blue crab, *C. sapidus,* classified as a commercial species. This economic classification is made rictly on the basis of minimum maturity size, and noncommercial species hich are of marketable size are not culled from the catch, but are processed as ue crabs.

Rathbun (1930) described each species and reported that the northern limit the range of each was: (1) *C. sapidus,* Nova Scotia; (2) *C. ornatus,* New rsey; (3) *C. danae,* Indian River Inlet, Florida; (4) *C. marginatus,* Florida eys.

Lunz (1958) reported that the morphological features usually given for xonomic separation of the species are variable, and individuals matching any the frontal outlines given by Rathbun can be found in South Carolina waters. unz also stated that only 30% of the crabs caught by trawlers on the South arolina coast are the blue crab, the remainder being presumably C. *ornatus* ıd *C. danae.*

We have found that along the coast of the southeastern Atlantic states, the on-commercial species are common at most times during the year, but ppear to be restricted to waters of higher salinity than are blue crabs. Those ken in North Carolina are *C. ornatus*, and possibly *C. danae*, and those ken in the St. Johns area are *C. ornatus*, *C. danae,* and possibly *C. marginatus*.

In any event, the distribution and identification of the non-commercial ecies, and the composition of the crab populations in our study area, are ıcertain. Identification of the larval forms of the different species is even ore complicated, and this creates a definite problem in our work, since etermination of the distribution of blue crab larvae requires correct identifi- ıtion.

arval Studies

The larval studies are basically of two types: (1) laboratory studies to etermine the effects of environmental factors on larval survival and rate of evelopment, and (2) field studies to determine the distribution and abundance larvae.

In the laboratory, larvae of the blue crab have been reared from hatching beyond the first crab stage (Costlow, Rees, and Bookhout, 1959). Larvae e now being reared under a variety of controlled conditions to determine how linity, temperature, and diet affect the survival of the larval stages and their te of development to the crab. There is considerable variability in the survival of larvae obtained from hatching the eggs of different female blue crabs. Survival has ranged from less than 1% to approximately 40%, even when all larvae are maintained under identical environmental conditions. This has made it difficult to show any direct correlation between survival of the zoeae and conditions which would normally be encountered in nature. It is possible that this variation in survival is associated with intrinsic factors such as diet of the female crab prior to egg laying, environmental factors at the time of egg laying, or genetic differences. Studies are underway to determine if variability of larval survival is associated with nitrogen content or other organic constituents of the eggs and larval stages. Additional work is needed to determine the cause of this variability in survival, and how the physiological condition of the female affects egg and larval development.

Recent work has established that mortality and rate of development of the megalops stage (that stage just prior to the first crab) are considerably affected by temperature and salinity. At 15C, the megalops rarely develop to the crab stage, while at 20, 25, and 30C, as high as 80% survive and complete metamorphosis to the crab stage. The rate of development is slower in megalops maintained in lower temperatures and lower salinities. This stage may be the most critical stage in larval development, as far as its tolerance to physical conditions of the environment is concerned.

Progress is also being made in hatching and rearing the noncommercial species of *Callinectes* and other closely related species in the laboratory. This work is essential if the larval forms from nature are to be correctly identified to species.

In our field studies, regular plankton collections are being made in estuarine and offshore waters in North Carolina and Florida. In addition, plankton collections from the Florida Straits to Cape Hatteras, North Carolina, taken over a 2 year period by the Bureau of Commercial Fisheries research vessel THEODORE N. GILL, were made available.

Our analysis of these plankton collections reveals the following:

(1) In the estuaries, only early stage zoeae and megalops occur. There is a tremendous drop in numbers from first to second stage zoeae. This may be comparable to the heavy mortality between first and second stage zoeae observed in laboratory rearing experiments.

(2) In the inlets, all larval stages occur. This suggests that some complete development takes place in these waters.

(3) The most productive waters for the combined larval stages are offshore In Florida, Georgia, and South Carolina, large numbers of early stage zoeae occurred near the beaches, but the most productive areas for the combined larval stages were 20 and 40 miles offshore. It is surprising to find relatively large numbers of late stage zoeae and megalops occurring 60 miles offshore and some as much as 80 miles offshore.

These findings raise many questions to which we do not have the answers Among them are:

(1) How can one account for the presence of megalops in the estuaries in the absence of late-stage zoeae in these areas? It seems unlikely that the megalops can make their way into the estuaries from 40 to 60 miles offshore before metamorphosis occurs.

(2) Do these larvae which are carried offshore, and this appears to be a large percentage of the larvae which are produced, successfully complet

velopment to the crab and subsequently contribute to the estuarine population juveniles and adults?

(3) Are the crabs which result from the development of these offshore vae lost to the fishery, or do they become part of an offshore population of *llinectes* crabs?

We believe that these and many other questions will be answered as the sult of our continuing larval studies. Such studies will also help us determine y fluctuations in abundance occur.

mature Crab Studies

We are routinely collecting information on the ecology of juvenile blue crabs. nce most of the gear employed in the commercial fishery is selective for adult abs, we must do our own fishing for immature crabs. This involves trawling ith fine-mesh trawls in the estuaries and offshore, and the use of haul seines the shallow bays and tributaries.

The immature crab studies have four major objectives: (1) To locate the rsery grounds for immature crabs and to determine their abundance, food, edators, and competitors. (2) To determine recruitment rates by measuring e abundance of immature crabs in certain size ranges. (3) To determine owth increment, time, and mortality between molts of the blue crab. (4) To velop a means of forecasting crab abundance in advance of the fishing season.

These are continuing studies conducted on a year-round basis so that sufficient ta can be collected to be meaningful.

ovements of Adult Crabs

The movements of sexually mature blue crabs are being determined from gging studies. Approximately twenty thousand have been tagged and released roughout our study areas. During tagging, a representative sample (usually ery fifth individual) is placed to one side and the gonads examined for the age of sexual maturity. This additional information makes it possible to rrelate the movements of the adults with mating activity.

It has previously been indicated that there is very little movement of blue abs between estuaries. There is, however, considerable movement of crabs ithin a particular estuary and into the adjacent coastal waters. The pattern these movements is similar in the two areas under study—Newport River, orth Carolina, and St. Johns River, Florida—therefore, a description of the sults obtained in the St. Johns River will suffice.

Our studies in the St. Johns cover an area extending from the mouth of the ver to Astor, Florida, a distance of 135 miles. Thirty miles from the mouth of e river, the salinity is zero, and about two-thirds of the St. Johns River blue ab fishery takes place in freshwater.

Mating of the St. Johns River blue crab occurs throughout the 135 miles the river under study. The period of mating is primarily March through ovember. Female blue crabs mate only once and this occurs immediately after e female sheds for the last time, and while she is still in the soft-shell state. erm will remain viable in the seminal receptacles of the female for at least year, to be used as often as she lays eggs, which is usually more than once.

Females which mate during the fall months in fresh water begin their igration to waters of low salinity in December. This results in a congregation females in December and January about 20 miles from the mouth of the ver. In February, the females migrate to waters of higher salinity about 10 miles from the mouth of the river and develop a sponge of eggs on the abdomen. During March and April, sponge females migrate into the ocean where the eggs hatch. The majority of these ocean migrants pass through the Inland Waterway (5 miles from the mouth of the St. Johns) and enter the ocean via the Ft. George and Nassau Rivers, approximately 6 and 15 miles to the north of the St. Johns. Soon after the eggs hatch, spent females re-enter the St. Johns, the Ft. George, and Nassau Rivers to develop a second sponge. The second sponge develops rapidly, and these females return to the ocean during June and July for the hatching of the eggs. Following the hatching of this second sponge, the females do not normally return to the river, but remain in the ocean and presumably die soon afterwards.

The foregoing describes the movements of one group of females that mates in September and October, and migrates to the ocean the following spring. However, there are three distinct groups of females in the St. Johns during any one year. A second group mates in spring and migrates to the ocean in the summer, while a third group mates in summer and migrates to the ocean in the fall. Each of these groups may be reinforced in the lower river and ocean by second-sponge females from the preceeding group.

Males which mature in fresh water, 35 to 135 miles from the mouth of the river, likewise migrate downriver toward and into higher salinity waters, throughout the year. This may be due, in part, to the presence of mateable females which are more closely associated with the saltier water of the lower river. Males in the lower 25 miles of the river usually remain in the area, but some movements do occur into the ocean and the Ft. George and Nassau Rivers throughout the year. In late fall and early winter, a concentration of males appears in the waters of the lower St. Johns and immediately off the mouth.

These migrations are reflected in the sex ratio of the commercial catch. In the lower 25 miles of the river, 45% of the catch is male and 55% female; from 25 to 75 miles from the mouth, the sex ratio is 80% male and 20% female; from 75 to 135 miles from the mouth, the catch consists of 88% male and 12% female.

From the studies of the larvae, juveniles, and adults described above, it is believed that a fairly complete picture of the complicated life history of the blue crab will emerge. This information, augmented by laboratory studies on the survival requirements of the various life history stages, will provide a foundation for the scientific management of the species.

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EXTRAIT

[redacted]

NORTH ATLANTIC FISH MARKING SYMPOSIUM
SPECIAL PUBLICATION NO. 4 (1963)
INTERNATIONAL COMMISSION FOR THE NORTHWEST
ATLANTIC FISHERIES

Reprinted from International Commission
for the Northwest Atlantic Fisheries
Special Publication No. 4
North Atlantic Fish Marking Symposium
held at Woods Hole, Mass., U.S.A., May, 1961
Issued from the Headquarters of the Commission
Dartmouth, Nova Scotia, Canada
1963

61.

An Initial Inquiry into a Photoelectric Device to Detect Menhaden Marked wit Fluorescent Pigments

By

JOHN W. REINTJES[*]

Introduction

Each year over 5,000,000,000 menhaden (*Brevoortia* spp.) are the raw material for the fish meal and oil industry of the Atlantic and Gulf coasts of the United States. Catching, handling, and processing are done by mechanical means, and there is no opportunity to detect marked fish visually. Therefore, mechanical or electronic methods are required to detect marked fish released into the fishable population.

Detection or recovery of tags by magnetic or electronic devices has been used for several herring-like fishes. Recovery of nickel belly and opercle tags from Pacific herring, *Clupea pallasii*, was reported by Rounsefell and Dahlgren (1933a, 1933b) and Dahlgren (1936). Magnetic recovery of tags was also employed in studies of the California sardine, *Sardinops caerulea*, (Clark and Janssen, 1945), the Norwegian herring, *Clupea harengus*, (Fridriksson and Aasen, 1950) and the Panama anchoveta, *Cetengraulis mysticetus*, (Klima and Bayliff, 1961). Recently, electronic devices for detection of ferromagnetic and radioactive tags were tested experimentally in the Pacific herring fishery (van Haagen and Dale, 1959; Anonymous, 1959).

Trials showed ferromagnetic tags to be unsuited to the menhaden fishery. An internal tag large enough to be recovered magnetically caused severe visceral damage to the fish, particularly among juveniles. In some menhaden reduction plants, magnetic recovery would be difficult as much of the solids is not pulverized into meal.

Marking young fish with biological stains, including luminescent[**] pigments, suggested the use of a photoelectric device for detection. Jackson (1959) used luminescent pigments for the mass marking of fish by spraying. Two recent publications have reported successful mass marking of salmon (Bouchard and Mattson, 1961) and a number of freshwater fishes (Deacon, 1961) by immersion. Marking juvenile menhaden with biological stains has shown that m staining by immersion or feeding might be possi (Carlson, unpubl. MS[***]).With these results in mi a device was designed and constructed by the Fishe Instrumentation Laboratory, Bureau of Commer Fisheries, Seattle, Washington. Results of an ini inquiry into the use of this device as a means detecting menhaden marked with fluorescent pigme are reported.

I wish to acknowledge the suggestions and techni assistance of Richard H. van Haagen, Gordon Esteberg, and other staff members of the Fishe Instrumentation Laboratory. Frank T. Carlson the Menhaden Program performed many of preliminary trials with the device.

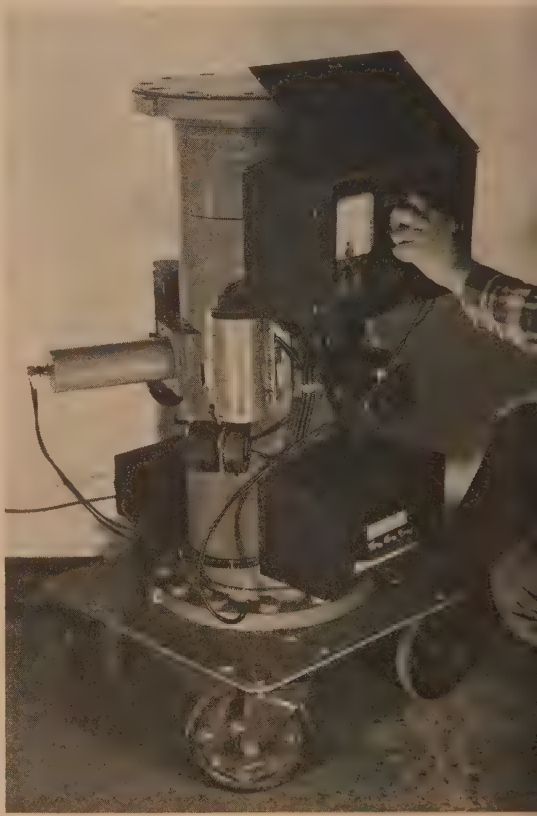

Figure 1. Fluorescent detector in the laboratory during operations.

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[**] Luminescence is classified as (a) fluorescence, if it lasts only during the period of excitation and (b) phosphorescence, if it persists when the exciting source is removed.

[***] "Preliminary results of experiments to mark juvenile menhaden with biological stains by immersion or feeding" by Frank T. Carlson, U. S. Bureau of Commercial Fisheries, Millville, Delaware.

General Description of the Device

The laboratory model of an electronic detector to neasure fluorescence was constructed with a three-oot section of steel pipe (inside diameter 10 in.) of the type used to unload menhaden from the boats at the reduction plants. The pipe was mounted upright on a steel platform 24 in. × 24 in. × $^1/_4$ in. (Fig. 1). Six ports, $2^1/_2$ in. × $2^1/_2$ in., were equally spaced around the middle of the pipe. A $3^1/_8$ in. × $3^1/_8$ in. filter housing was mounted at each port. To each of three alternate ports was mounted an ultraviolet transmitting filter (Corning No. 5860), and an ultraviolet lamp (General Electric S-4) with an adjustable aperture and a cooling fan. To each of the remaining ports was mounted a plate with a $2^7/_8$ in. × $^3/_4$ in. ring adapter for attachment of the multiplier phototube, viewing eyepiece, or fiber cap. One or more filters were mounted at each detection port to cut off ultraviolet light. A ten-stage multiplier phototube (DuMont Type 6292) with a flat end-window photocathode was mounted in a brass shield. Gelatin or glass filters (Eastman Kodak, Wratten Nos. 8, 9, 15, and 16 and Corning Nos. 3486 and 4308) were used to block ultraviolet light from reaching the photocathode.

The electronic equipment was mounted around the outside of the pipe and on the platform. The upper box (Fig. 2) contains a modified audio vacuum tube voltmeter (Heathkit Model AV-3), an amplifier with a hundredfold gain, high and low voltage power supplies, threshold control, coarse sensitivity control, master switch, and storage space for the multiplier phototube and cables. The lower box contains ballast transformers and individual switches for the ultraviolet lamps. A transformer to provide constant line voltage to the upper box only was mounted on the platform. A schematic diagram of the electronic circuits is shown in Appendix 1a—b. A list of

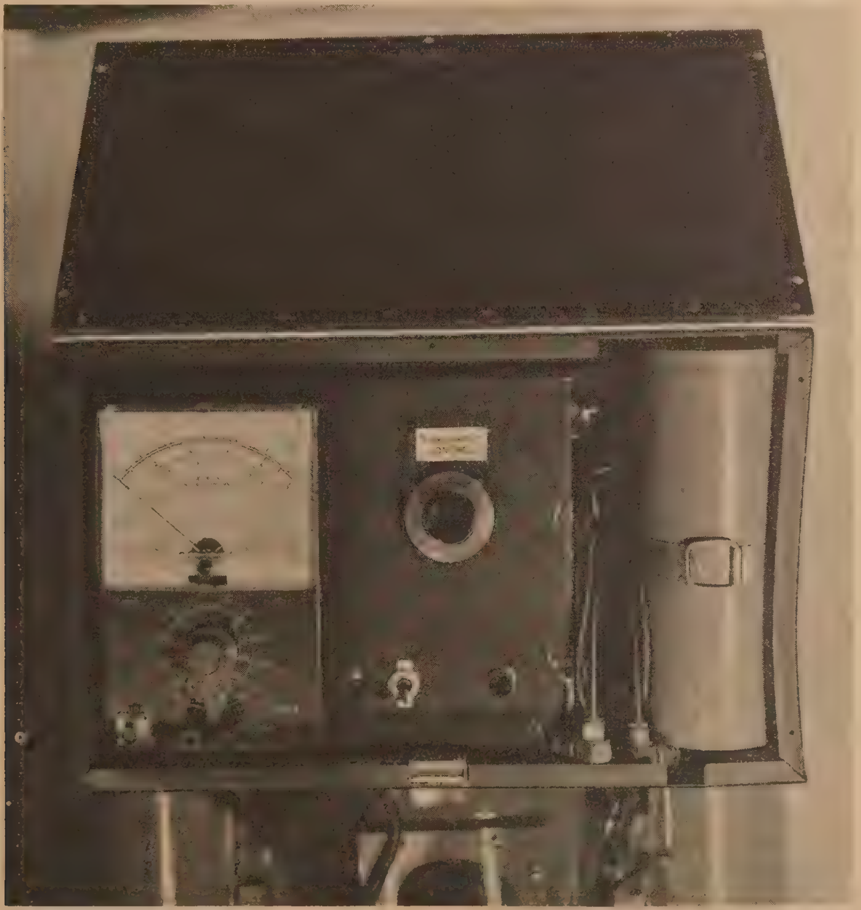
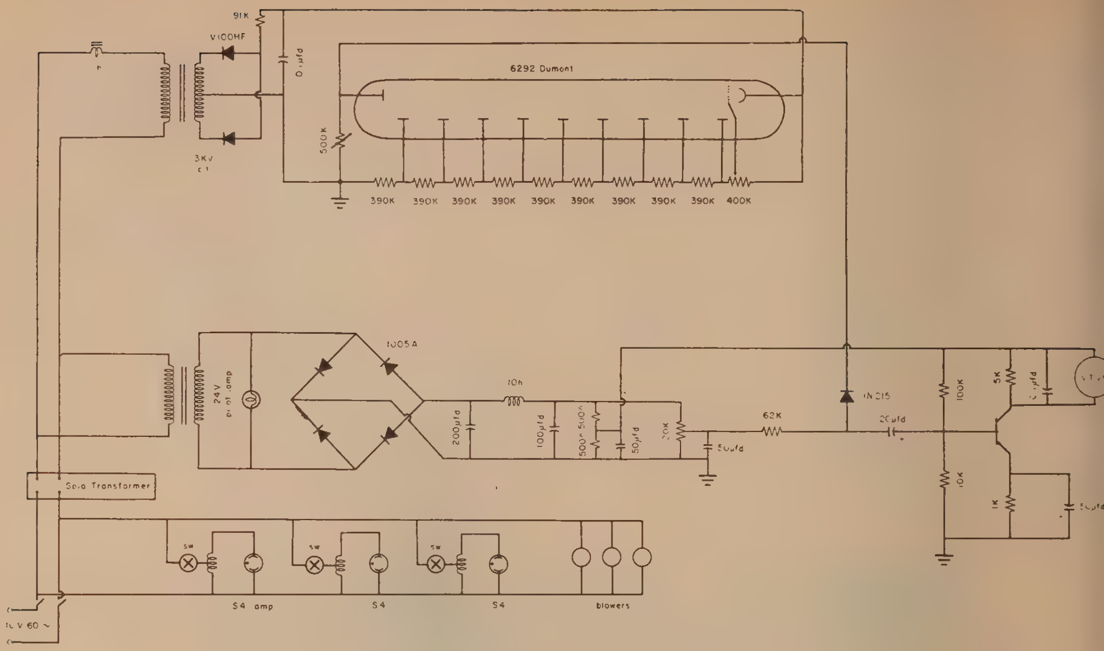


Figure 2. Close-up view of the upper control box with the multiplier phototube and cables in the storage position.



Appendix 1a. Schematic diagram of electronic circuit

equipment, manufacturers, and additional specifications is provided in Appendix 2.

Operating Trials and Results

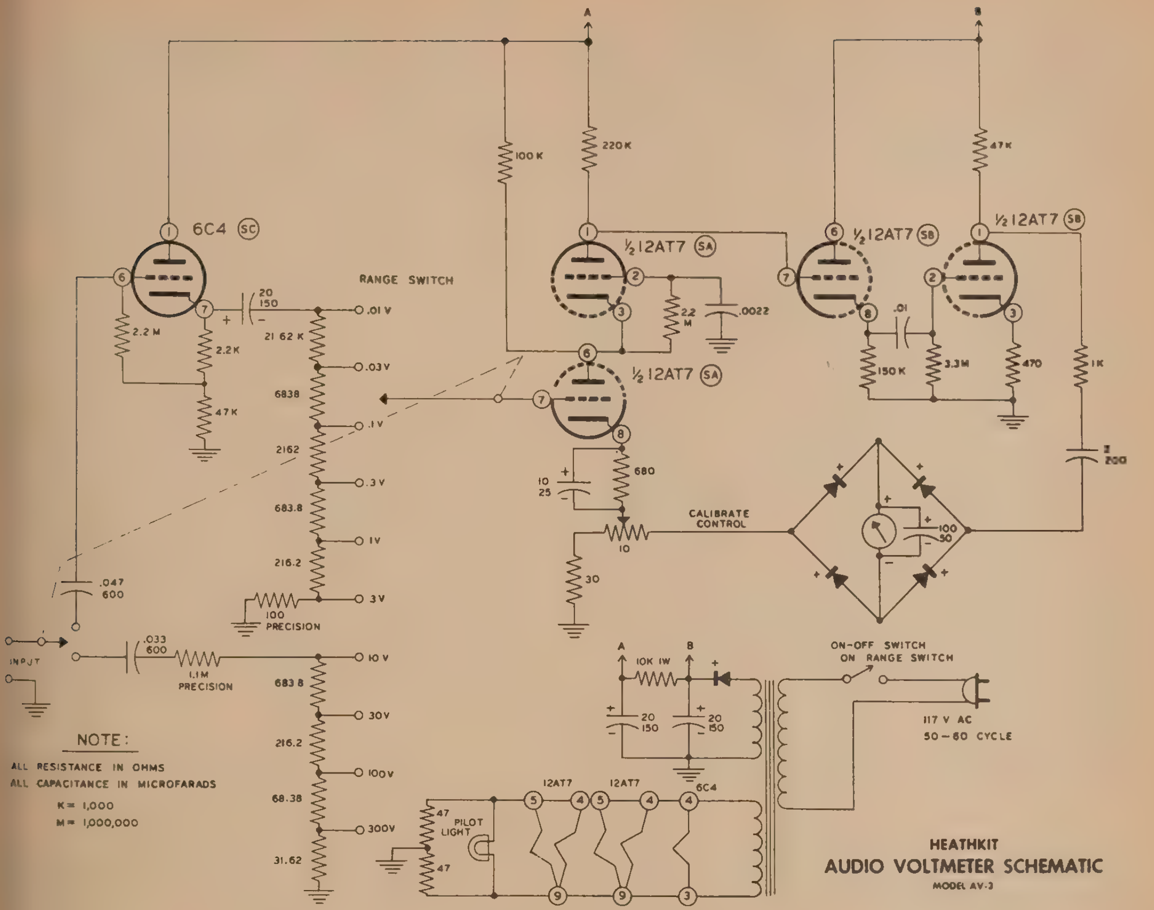
Operating characteristics of the device were determined for different combinations of ultraviolet light and cut-off filters. Background light excited the multiplier phototube to give a voltmeter reading when the pipe was empty and sealed from all external illumination. The threshold control was turned to suppress the reading. It was learned that background came, principally, from three fluorescent sources: (1) the inner surface of the pipe, (2) dust, bacteria, and similar particles suspended in the air, and (3) the ultraviolet cut-off filters. Of these, the last was of major concern because of the magnitude of the photoresponse.

A filter was mounted at each detector or viewing port to cut off ultraviolet light from reaching the photocathode. Initially, a K-2 (Wratten No. 8) gelatin filter, mounted between two pieces of plate glass, was used. The filter fluoresced from the diffused ultraviolet light to give a relatively high background reading. This was eliminated by the threshold control. However, when ultraviolet light was reflected from a non-fluorescent object, the incident rays caused the filter to fluoresce above the background level. The response to reflected ultraviolet light on the filter often exceeded the signal from fluorescent objects, which made it impossible to disting between the two. Other gelatin filters were tried all gave similar results.

A glass filter (Corning No. 3486) was substitu for the K-2 gelatin filter. The glass filter also fluores but at a much lower intensity; the ultraviolet li therefore, could be increased to where the differe between the diffused and reflected ultraviolet less pronounced and the effect of either could suppressed by the threshold control. To fur dampen the effect of the fluorescing filter, ano glass filter (Corning No. 4308) was placed betw the cut-off filter and the photocathode. The sec (Corning No. 4308) filter was selected to cut off n of the yellow-orange light emitted by the first (Corn No. 3486). The Corning No. 4308 also fluores but with such low intensity as to be easily suppre with the threshold control.

Trials were run to determine the photorespo of the multiplier phototube to inorganic and orga substances exposed to ultraviolet light. Objects v suspended level with, or dropped past, the ph cathode. Nearly all materials tested fluoresced emit some visible light.

A preliminary screening of materials was condu to determine the operational performance limitations of the device and the fluorescent p perties of commonly occurring substances, dyes pigments, and marine organisms. The objects v


A
B
6C4 SC
100 K
220 K
47 K
½ 12AT7 SA
½ 12AT7 SB
RANGE SWITCH
20 150
.01 V
.03 V
.1 V
.3 V
1V
3 V
10 V
30V
100V
300V
21 62 K
6838
2162
683.8
216.2
100 PRECISION
2.2 M
2.2K
47K
2.2 M
.0022
.01
150 K
3.3M
470
1K
2 200
10 25
680
CALIBRATE CONTROL
10
30
100 50
.047 600
.033 600
1.1M PRECISION
INPUT
683 8
216.2
68.38
31.62
NOTE:
ALL RESISTANCE IN OHMS
ALL CAPACITANCE IN MICROFARADS
K= 1,000
M= 1,000,000
10K 1W
20 150
20 150
ON-OFF SWITCH ON RANGE SWITCH
117 V AC
50—60 CYCLE
12AT7
12AT7
6C4
47
PILOT LIGHT
47
HEATHKIT
AUDIO VOLTMETER SCHEMATIC
MODEL AV-3

Appendix 1b. Schematic diagram of electronic circuit (continued)

suspended in the center of the pipe, level with the apertures of the ultraviolet lamps and the photocathode window. The objects were rotated until a maximum response registered on the voltmeter. A tabulation of the findings is presented in Appendices 3, 4, and 5.

The device detected and measured fluorescent light over a wide range of intensity and color. Fluorescent substances of low intensity, as well as especially prepared pigments of high intensity, were apparently within the performance range of the instrument. No limitations appeared within the response range of 2 to 3000 mv for a background setting of 200 mv. No readings in excess of 3000 mv were obtained with the pigments and light source tested.

Fluorescence occurred in most substances examined in the laboratory (Appendix 3). Inorganic objects, such as glass, metal, and tap water, fluoresced a small, but detectable amount. Pigmented glass filters, glass mirrors, and sand each fluoresced to some extent. Organic substances including paper, cellulose, polyethelene films, and other plastics varied widely in fluorescence. Pigments and dyes also varied widely; especially prepared fluorescent pigments effected near the maximum response obtainable with the ultraviolet source and instrument settings employed (Appendix 4). Less than maximum response (ca. 3000 mv) was obtained from several fluorescent pigments. This might be due to the emission spectra and the blocking effect of the cut-off filters.

The natural fluorescensce of marine animals, especially the fishes, was of primary importance to the inquiry. Laboratory trials were limited to a few fishes and marine invertebrates (see Appendix 5) commonly occurring in the vicinity of Beaufort, North Carolina. The results showed that fish and other marine organisms fluoresce with varying intensity by species.

Additional trials were run to determine the maximum velocity at which fluorescent objects could pass the photocathode and still be detected. The results showed that objects marked with fluorescent dyes could be detected up to a velocity of 30 feet per second. Higher velocities were not tried because those tested exceeded the maximum expected in menhaden reduction plants.

Conclusions from Preliminary Inquiry

The laboratory model of an electronic detector for fluorescent objects measured the emitted light over a wide range of intensity. Fluorescence was common to all organic substances tested and probably occurs naturally in all animals and plants. The detection of marked animals may depend upon the relative intensity and spectral emission. Furthermore, the model detected fluorescent objects moving at velocities expected within the fish exhaust pipes at menhaden reduction plants.

Phosphorescent rather than fluorescent pigments might be used to mark menhaden. Phosphorescence can be detected by the device if modified so that the ultraviolet light and the multiplier phototube alternately are turned on and off, 60 or more times a second.

Further studies are needed to determine whether sufficient separation of intensity or spectrum exists between artificial and natural luminescence.

Future Work and Prospects

The results and conclusions from the initial inquiry have shown the need for further studies. The extent of these inquiries and the progress made toward the ultimate solution of the problem to mark and detect menhaden with luminescent pigments will depend upon the satisfactory completion of each successive phase. Briefly, the studies needed are:

1. Spectrophotometric survey of marine organisms encountered in the menhaden landings, to determine the intensity and spectra of naturally occurring fluorescence and phosphorescence. The purpose is to discover a spectral gap and a difference of intensity that could be occupied with an introduced pigment.
2. Selection of luminescent pigments and narrow-band-pass filters determined from the spectrophotometric survey.
3. Application of selected pigments to menhaden to determine methods, toxicity, and retention.
4. Screening trials with the electronic detection device.

The development of a method of marking menhaden and a device for detecting these marked fish during mass production of fish meal and oil depends on the satisfactory solution of several successive and dep
dent problems. Any conclusions concerning
functional application and detection of lumines
marks must be withheld until the completion
additional studies. However, the results of the in
studies indicated that the device may be usec
a laboratory or field instrument for short-t
marking experiments with menhaden, even tho
the ultimate use as an automatic detector in menha
reduction plants may not be realized.

Summary

A photoelectric device to detect menhaden mar
with fluorescent pigments was constructed and t
in the laboratory. The occurrence of natural fluc
cence in menhaden and other marine organi
made the discrimination of marked menha
impractical without further modifications of
device. The conclusions reached from the prelimir
trials were (1) that phosphorescent rather t
fluorescent pigments should be used and (2)
narrow-band-pass filters might be employed
distinguish marked fish. Future studies were prop
to make the device functional for experimenta
field use.

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Appendix 2
List of equipment and manufacturers

Electric cooling fan
Type 69 C F. A. Smith Manufacturing Company
Rochester, N. Y.

Audio vacuum tube voltmeter
Heathkit AV-3 Heath Company
Benton Harbor, Mich.

Multiplier phototube
DuMont type 6292 10-stage with $1^1/_2$ inch flat end window photocathode having a S-11 spectral response.
Allen B. DuMont Laboratories Inc.
Clifton, N. J.

Glass filters
Ultraviolet transmitting Corning Glass No. 5860 (C.S. 7—37)
Blue-green filter Corning Glass No. 4308 (C.S. 4—70)
Cut-off filter Corning Glass No. 3486 (C.S. 3—69)

Corning Glass Works
Corning, N. Y.

Gelatin filters
Wratten No. 8 K-2 Eastman Kodak Co.
Wratten No. 9 K-3 Rochester, N. Y.
Wratten No. 15 G
Wratten No. 16

Ultraviolet lamp
S-4 100 watt General Electric Co.
Schenectady, N. Y.

Constant voltage transformer
Sola No. 3003 95 v.—125 v. 115 v.
Sola Electric Co.
Chicago, Ill.

Autotransformer (ballast) for 100 watt H or S-4 mercury vapor lamp.
General Electric Model No. 9T64Y3518
General Electric Co.
Fort Wayne, Ind.

Appendix 3
Fluorescent photoresponse (mv) to inorganic and organic objects. (ultraviolet background light — 200 mv)

Object	Size	Photo-response
Glass miror	25 mm × 25 mm	5
Plate glass	80 × 80 × 5 mm	50
Pyrex test tube	50 ml	0
Aluminium foil	25 mm × 25 mm	50
Distilled water in Pyrex test tube	50 ml	0
Tap water in Pyrex test tube	50 ml	10
Filtered sea water in Pyrex test tube	50 ml	150
Unfiltered sea water in Pyrex test tube	50 ml	200
Beach sand in Pyrex test tube	50 ml	50
Millipore filter	22 mm diameter	5
Millipore filter	47 mm diameter	150
Filter paper		
Eaton and Dikeman No. 615	25 mm × 25 mm	700
Whatman No. 40	25 mm × 25 mm	400
Whatman No. 42	25 mm × 25 mm	300
Ping-pong ball	37 mm diameter	900
Saran plastic film	25 mm × 25 mm	20
Polyethylene film	25 mm × 25 mm	50

Appendix 4
Fluorescent photoresponse (mv) to synthetic pigment colors. (ultraviolet background light — 200 mv)

Object	Size	Photo-response
Derbylite[1] fluorescent pigment colors		
N 580, N 590, N 600	25 mm × 25 mm	3200
N 100, N 108, N 410, N 490, N 500, N 520, DO 531, N 560, D 589, D 610, DO 615, DO 616, N 630, DO 660	25 mm × 25 mm	3000
DO 491, DO 530, N 570, N 650	25 mm × 25 mm	2800
DO 585, N 620	25 mm × 25 mm	2500
DO 480	25 mm × 25 mm	2300
N 651	25 mm × 25 mm	1500
DO 670, DO 673, DO 674	25 mm × 25 mm	1000
Paulite[1] phosphorescent materials		
1207	25 mm × 25 mm	2800
1218	25 mm × 25 mm	1500

[1] Trade names for products of Luminous Resins, Inc. 166W. Washington St., Chicago, Ill.

Appendix 5
Fluorescent photoresponse (mv) to marine organisms.
(ultraviolet background light — 200 mv)

Common name	Scientifiic name	Number of specimens	Size range (mm)	Mea photores (mv
Atlantic menhaden	*Brevoortia tyrannus*	5	93—103 F.L.[1]	23
Yellowfin menhaden	*B. smithi*	3	270—275 F.L.	300
Planehead filefish	*Monacanthus hispidus*	2	130—169 F.L.	250
Northern searobin	*Prionotus carolinus*	4	105—225 F.L.	210
Scorpion fish	*Scorpaena* sp.	2	132—140 F.L.	130
Bluefish	*Pomatomus saltatrix*	2	168—181 F.L.	100
Spot	*Leiostomus xanthurus*	1	182 F.L.	190
Northern puffer	*Sphaeroides maculatus*	1	130 F.L.	140
Summer flounder	*Paralichthys dentatus*	2	196—250 F.L.	300
Butterfish	*Poronotus triacanthus*	3	113—143 F.L.	100
Weakfish	*Cynoscion regalis*	1	224 F.L.	140
Atlantic croaker	*Micropogon undulatus*	2	200—215 F.L.	180
Clearnose skate	*Raja eglanteria*	1	350 T.L.[2]	230
Atlantic squid	*Loligo peali*	1	154 M.L.[3]	260
White shrimp	*Penaeus setiferus*	1	52 C L.[4]	130
Mantis shrimp	*Squilla empusa*	1	60 C.L.	160
Swimming crab	*Portunus* sp.	2	45—70 C.L.	300
Rock shrimp	*Sicyonia* sp.	2	47—50 C.L.	220
Keyhole urchin	*Mellita testudinata*	2	101—109 diameter	
Starfish	*Astropecten* sp.	2	90—93 diameter	80

[1] F.L. — fork length
[2] T.L. — total length
[3] M.L. — mantle length
[4] C.L. — carapace length

Schmidt & Klaunig, Kiel

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Reprinted from TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY
Vol. 92, No. 3, July, 1963
pp. 320–322

Gas-Bubble Mortality of Fishes in Galveston Bay, Texas

WILLIAM C. RENFRO

Gas-Bubble Mortality of Fishe
in Galveston Bay, Texas[1]

Gas-bubble "disease" in fish may re
when their external environment is supers
rated with dissolved atmospheric gases. M
specifically, the sum of the individual tensi
of the gases dissolved in the water must
ceed the hydrostatic pressure (Duodor
1957). Under these conditions the fish's b
fluids become supersaturated, and excess
is soon released internally in the form
bubbles. These bubbles then circulate
the blood and gradually accumulate at
strictions. Since there is a continuous sup
of dissolved gas diffusing from the water
the fish, the process continues until blood
culation is stopped.

The disease is occasionally encountered
hatcheries and fish-culture stations which
waters with high concentrations of dissol
gases, and special measures are required
prevent mortalities in these situations (D
nevig and Dannevig, 1950; Harvey and Sm
1961).

At least two natural mortalities of fish
to gas-bubble disease have been report
Woodbury (1941) described a fish kill cau
by gas-bubble disease in black crappies, ot
centrarchids, northern pike, walleyes,
cyprinids in Lake Waubesa, Wisconsin.
noted dissolved oxygen concentrations as h
as 327 percent of saturation, resulting fr
a dense bloom of *Chlamydomonas*. The fis
affected were mostly large mature adults;
small or young fish died. Rukavina
Varenika (1956) reported death of "Cali
nian and stream trouts" caused by gas-bub
disease in two shallow ponds at the springs
the River Bosna, Yugoslavia. The disease
curred during hot sunny weather in late J
1956, when oxygen production from ph
synthetic activity was especially high. No
solved oxygen values were reported.

MORTALITY IN GALVESTON BAY

On the morning of January 14, 1959,
estimated 300 spotted seatrout, *Cynosc
nebulosus*, were found floating in upper

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[1] Contribution No. 175, U. S. Bureau of Commer
Fisheries Biological Laboratory, Galveston, Tex

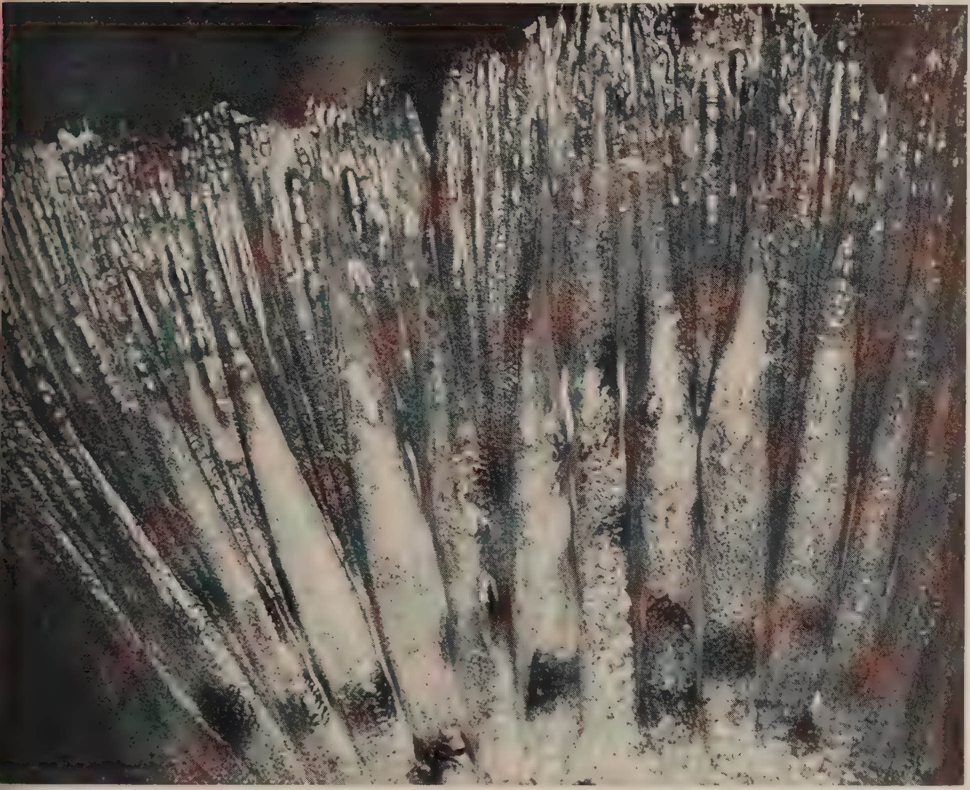

FIGURE 1.—Caudal fin of seatrout showing gas bubbles.

ston Bay. The dead seatrout were nearly all rge. A sample of 23 had a mean standard ngth of 50 centimeters and a mean weight of 2 pounds. Other dead fishes noted were stlarval largescale menhaden, *Brevoortia tronus*; bay anchovies, *Anchoa mitchilli*; venile Atlantic croakers, *Micropogon undu- tus*; small eels, probably *Myrophis punc- tus*; and a longnose gar, *Lepisosteus osseus.* he fish had apparently died during the previ- s night, as rigor mortis had not yet oc- rred. They were being pushed toward shore wind and wave action.

Although no external or internal physical juries were evident, unusual features of the ad seatrout were the presence of excessive ucus on the body, bright red gills, distended im bladders, and blisters containing gas in rious parts of the body. These blisters were esent within the membranes connecting fin ys (Figure 1) and occasionally under the skin on the sides of the body. Microscopic examination of the gills revealed most of the branchial arterioles to be completely filled with gas bubbles, which entirely displaced blood in the gill vascular system. Occlusion of blood circulation was presumed to be the primary cause of death.

This fish kill was observed in a portion of Galveston Bay which at times receives pollutants from the Houston Ship Channel, yet extensive chemical analyses for harmful toxicants all proved negative. Also, test fishes placed in samples of the water from the kill area lived for several months without apparent ill effects. Inspection of the area showed that water in this part of the bay was very turbid and colored rust-brown as a result of a dense plankton bloom. The predominant plankters, present in approximately equal numbers, were identified as a euglenoid, *Eutreptia* (*marina*), and two dinoflagellates, *Prorocentrum cutel-*

lum and *Gymnodinium (symplex)*. Dissolved oxygen concentrations remained near 250 percent of saturation throughout the day.

Prevailing climatic and hydrographic conditions favored the development and maintenance of very high dissolved-oxygen concentrations and, perhaps, supersaturation with nitrogen and other gases as well. For several days prior to the kill there was little cloud cover, and the resulting high insolation promoted intense photosynthesis. Winds were generally light and variable, barometric pressure was high but decreasing, and water temperatures were low but increasing. Under these conditions the body fluids of the fishes took on oxygen (or a mixture of atmospheric gases) in excess of their saturation values, and the surplus came out of solution as bubbles. The bubbles then accumulated, forming larger bubbles and obstructing circulation.

ACKNOWLEDGMENTS

I am greatly indebted to Warden R. Z. Finchum for the photograph used herein, and to Mr. Howard T. Lee, Director, Field Operations, Texas Game and Fish Commission, for permission to use data reported in the 1958–59 Annual Report of the Commission's Marine Division. My sincere thanks go to Mr. A
ander Dragovich, U. S. Bureau of Commercial F
eries, St. Petersburg Beach, Florida, for his excel
translation from the Slavic of the paper by Ruka
and Varenika. William B. Wilson, Bureau of C
mercial Fisheries, Biological Laboratory, Galves
Texas, kindly identified the organisms present in
observed phytoplankton bloom.

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Made in United States of America
Reprinted from The Auk
Vol. 80, No. 2, 16 April 1963
pp. 196–197

Birds associating with elephants and hippopotamuses.—The well-known association of Cattle Egrets (*Ardeola ibis*), Red-billed Oxpeckers (*Buphagus erythrorhynchos*), and Yellow-billed Oxpeckers (*B. africanus*) with the larger hoofed mammals is conspicuous throughout the plains and savannas of East Africa. However, on occasion other species of birds also exploit the ecological niche afforded by large mammals. On a recent trip to Kenya, Uganda, and Tanganyika, I observed three other species of birds feeding in close association with large ungulates:

Fork-tailed Drongo, *Dicrurus adsimilis.*—The country around "Bushwhackers," Hugh R. Stanton's camp on the Athi River 25 km north of Kibwezi, Kenya, is typical *nyika*, or tropical lowland bush. Drongos are a common and conspicuous member of the avifauna. Bush elephants (*Loxodonta africana africana*) are seasonally abundant; during my stay at the end of the long dry season, a few herds could usually be found feeding every morning and evening within hearing distance of the camp clearing. In the *nyika*, stalking is easy; I often sat quietly and watched feeding elephants for an hour or more, from as close as 30 m, with 7 × 35 binoculars. On two occasions, drongos accompanied the elephant herds.

On 2 October 1960, five drongos accompanied a herd of nine elephants which I watched from 1620 to 1730 hours. The birds perched on branches about one to two meters directly above the elephants. Whenever an elephant tore a branch from a tree, the drongos repeatedly darted, flycatcher-fashion, to snap up the insects which were dislodged from the branches, and returned to a perch above the elephants. During the 70 minutes I watched them, the elephants slowly moved about 0.25 km; the drongos remained with them the entire period.

On 16 October 1960, between 1650 and 1820, I watched two feeding elephants. Four drongos accompanied them, perching beside them in the low scrub about a meter from the ground. They frequently darted towards the elephants, and appeared to be catching tsetse flies (*Glossina* sp.) which were attracted to the elephants, rather than insects which the elephants disturbed.

Drongos have not previously been reported accompanying large mammals, but according to J. P. Chapin (*Bull. Amer. Mus. Nat. Hist.*, 75: 352, 1939), *Dicrurus paradiseus* follows troops of macaques (*Macaca* sp.) in Borneo, and *Dicrurus leucops* accompanies crested macaques (*Cynopithecus niger*) in Celebes. A Philippine drongo has earned the name "sentinel of the monkeys" because of this habit (A. L. Rand. *Fieldiana: Zoology*, 36: 23, 1954).

Piapiac, *Ptilostomus afer*.—The savannas bordering the Victoria Nile, in the Acholi and Bunyoro districts of Uganda, support a large population of forest elephants (*Loxodonta africana cyclotis*). Piapiacs, black magpie-like corvids, are fairly common, and frequently perch on the backs of elephants. For example, at 0845 on 20 October 1960, I saw more than 20 piapiacs with a herd of 17 elephants; at least one bird was on the back of each elephant. On the morning of 23 October 1960, I saw one red-billed immature and eight black-billed adult piapiacs on the back of a bull elephant. The birds are very adept at crawling over elephants, and can cling to the nearly vertical sides of their heads and bodies. They picked something—perhaps ticks, lice, or tsetses—from the skin of the elephant; they did not seem to be taking insects disturbed by the elephants. I never saw oxpeckers on elephants, nor piapiacs on other game.

Piapiacs have not previously been reported associating with elephants, but D. A. Bannerman (*The birds of tropical west Africa.* Vol. 6. London, Crown Agents for the Colonies, 1948. P. 38) says they follow herds of cattle, sheep, goats, donkeys, and wild game, for the insects disturbed by the animals. C. W. Mackworth-Praed and C. H. B. Grant (*Birds of eastern and northeastern Africa.* Vol. 2. London, Longmans, 1955. P. 679) state that in Sudan piapiacs are closely associated with domestic animals.

Common Sandpiper, *Tringa hypoleucos*.—I found this winter visitant from Eurasia moderately common along the Victoria Nile, one to eight km below Murchison Falls, 20 to 24 October 1960; and also in Lake Edward and along the Kazinga Channel, Toro and Ankole districts, Uganda, 25 to 28 October 1960. Hippopotamuses (*Hippopotamus amphibius*) were abundant; during the day they rested in small groups at the surface of the water. Common Sandpipers habitually alighted on the broad backs of the hippos, and patroled the "shoreline." Apparently they were not seeking ectoparasites, but aquatic organisms that drifted past. The bare backs of the hippos apparently offered a less obstructed base of operations than did the heavily vegetated shoreline. R. Verheyen (*Monographie éthologique de l'hippopotame.* Bruxelles: Institut des Parcs Nationaux du Congo Belge, 1954. P. 54) has observed this association in the Semliki River, Congo.—DALE W. RICE, *U. S. Fish and Wildlife Service, Sand Point Naval Air Station, Bldg. 192, Seattle 15, Washington.*

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PACIFIC COAST WHALING AND WHALE RESEARCH

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Reprinted from Transactions of the Twenty-Eighth North American Wildlife and Natural Resources
Conference, March 4, 5 and 6, 1963. Published by the Wildlife Management Institute,
Wire Building, Washington 5, D. C.

PACIFIC COAST WHALING AND WHALE RESEARCH

DALE W. RICE[1]

U. S. Fish and Wildlife Service,
Marine Mammal Biological Laboratory, Seattle 15, Washington

At the 25th North American Wildlife Conference in 1960, Richard M. Laws (1960) presented a paper on the problems of worldwide whale conservation, with particular emphasis on the Southern Hemisphere. Since that time, the Southern Hemisphere stocks of baleen whales have continued to decline at an accelerating rate, as was predicted by biologists. A drastic curtailment of the catch will be necessary to maintain the remnant stocks at even their present levels. Fleets of factory ships and catcher boats represent a capital investment of millions of dollars. If they can no longer operate at a profit in the Antarctic, some of them may turn to the North Pacific. We do not know how much exploitation the North Pacific whale stocks can withstand. It is appropriate now to look critically at the U.S. whaling industry and at our whale research program, so that we may anticipate future research and management needs.

WHALING IN THE UNITED STATES

There is not enough time to go into the long and fascinating history of whaling in the United States, and I must therefore restrict myself to active whaling operations. Whaling is conducted from three commercial whaling stations on the Pacific Coast; and by the Eskimos of the Alaskan villages of Barrow, Point Hope, and Wainright, who use aboriginal methods to take bowhead whales (*Balaena mysticetus*) and gray whales (*Eschrichtius gibbosus*). Only commercial whaling will be discussed here.

In 1956, the Del Monte Fishing Company opened a whaling station on San Francisco Bay at Point San Pablo, Richmond, California. It operated two catcher boats that year, and added a third to the fleet in 1957. In 1958, the Golden Gate Fishing Company opened another station, also on Point San Pablo, with one catcher boat. A second boat was added in 1959. From 1959 through 1962 all five catcher boats operated out of Point San Pablo. A third company, Bioproducts, Inc., of Warrenton, Oregon, was licensed as a whaling station in 1961. This firm engaged in whaling only as a sideline, and its one vessel took only four whales in 1961 and one in 1962.

These 3 shore stations on the Pacific Coast of the United States represent only a small proportion of the whaling effort in the North Pacific. Other nations operate 25 shore stations and 3 floating fac-

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[1] In the absence of the author, this paper was read by Mr. Karl W. Kenyon.

tories, employing 77 catcher boats. These include 2 shore stations
the Ryukyu Islands, 18 in Japan, 4 in the Kurile Islands, and 1
Vancouver Island. Japanese companies operate two floating fa
tories (the *Kinjyo Maru* and the *Kyokuyo Maru*) in the Bering S
and Aleutian area, and the Government of the U. S. S. R. operat
one floating factory (the *Aleut*) in waters off Kamchatka.

Six species of whales are brought in more or less regularly to t
U. S. whaling stations. These include four species of baleen whales-
the blue (*Balaenoptera musculus*), the fin (*B. physalus*), the sei (
borealis), and the humpback (*Megaptera novaeangliae*); and tv
species of toothed whales—the sperm (*Physeter macrocephalus*
and the giant bottlenose (*Berardius bairdi*). In addition, o
killer whale (*Orcinus orca*) was taken recently. Complete catch st
tistics of the California stations for the years 1956-62 are presented
Table 1. The average annual catch on our west coast has been som
what less than 300 whales; this amounts to less than 3 per cent of t
total North Pacific catch, which included 10,694 whales in 1961 (t
last season for which complete figures are presently available). Th
included 92 blue whales, 1,876 fin whales, 955 sei whales, 500 hum
back whales, and 7,271 sperm whales. The catch has remain
fairly stable in recent years.

The United States, along with most whaling nations, is a party
the 1946 International Convention for the Regulation of Whalin
Regulations provide that shore stations may take baleen whales f
only six months out of each year, sperm whales for eight. From 19
through 1959, the season for baleen whales on our west coast w
from 1 May to 30 October. Beginning in 1960, it was advanced to t
period from 16 April to 15 October. The season for sperm whales h
been 1 April to 30 November each year since the stations opened. T
international regulations also fix minimum size limits. For sho
stations producing fresh meat to be utilized in the country of origi

TABLE 1. NUMBER OF WHALES TAKEN BY THE TWO CALIFORNIA SHORE
STATIONS, 1956-62

Year	Blue	Fin	Sei	Humpback	Sperm	Bottlenose	Total
1956	....	3	....	133	9	....	145
1957	....	22	1	199	14	1	237
1958	26	109	2	115	8	1	261
1959	5	108[a]	37[a]	140	17	2	309
1960	1	138	47	67	16	2	271
1961[b]	2	118	51	62	101	4	338
1962[b]	2	123	22	39	60	....	247
Total	36	621	160	755	225	10	1,808

[a] These figures differ from those in the International Whaling Statistics, because two whales were erroneously reported as sei whales.

[b] The catch in Oregon was: 1961—2 humpbacks and 3 sperms; 1962—1 fin.

[c] Includes one killer whale.

these limits are 19.8 m. (65 ft.) on blue whales, 15.2 m (50 ft.) on fin whales and 10.7 m. (35 ft.) on sei, humpback, and sperm whales. It is forbidden to kill females accompanied by calves. Certain species—the gray, right, and bowhead whales—are completely protected from commercial whaling.

The methods used by the California whaling stations are basically the same as those employed by shore stations in other parts of the world. The vessels scout the area within about 230 km. (125 nautical miles) of the Golden Gate. When a "blow" is sighted, the whale is pursued and killed with a harpoon from a 90-mm. gun mounted on a platform on the bow. The head of the harpoon is a grenade, the explosion of which often kills the animal outright. California whalers have developed a unique harpoon head, consisting of an iron pipe about 8 cm. in diameter and 24 cm. long. The front end is beveled on the inside to form a sharp cutting edge. A metal disc, recessed several centimeters, plugs the front aperture and retains the black-powder charge. This head has two advantages over the standard pointed, cast-iron head: (1) it is much less likely to ricochet when it strikes obliquely; (2) it does not shatter and leave fragments in the meat which might damage the grinder.

After the whales are killed they are tied alongside the vessel, tail toward the bow, and are towed to the station. Sometimes several are towed together. They may be flagged and set adrift while the vessel continues to hunt. If the meat is to be saved, the animals must be flensed within 20 hours of death.

At the station, a chain or strap is secured around the whale's tail, against the base of the flukes, and a winch hauls the carcass up a slipway onto the flensing deck. Flensing follows the standard procedure originally developed by the Norwegians. The meat is cut into chunks and cooled in tanks of chilled salt water, and is then ground, packaged, and frozen. The blubber, viscera, and bones are chopped up in a rotary prebreaker. This machine was designed by the superintendent of one of the local whaling plants. The other California station has also installed one. These machines have greatly speeded up operations and reduced the need for manpower. Basically, they consist of a row of heavy, square, stationary, steel teeth which protrude upwards; immediately above and parallel to the teeth is a steel axle, which also bears a row of helically arranged teeth. As the axle rotates, the upper teeth successively sheer between the lower teeth. The bones, blubber, and viscera, are fed into the machine; when this material is engaged by the rotary teeth it is crushed and cut between the stationary teeth. An entire skull or vertebral column can be accommodated. A screw conveyor loads the ground material into a truck for hauling to the rendering plan

Whale products used in the United States include meat, meal, wha oil (*i.e.*, baleen whale oil), and sperm oil. The Oregon station als produces condensed solubles. Fresh meat is the most important proc uct of the California stations; baleen whale meat is used as a ingredient in canned pet food, and the meat of both sperm and balee whales is used on fur farms for mink feed. Whale oil is used in th United States as a poultry feed supplement and in paint. Sperm o has a wide variety of specialized industrial uses. Meal, a by product of oil production, is used in poultry feed and as a fertilize

The value of California whale catch has varied annually from fou hundred thousand to nine hundred thousand dollars (Table 2).

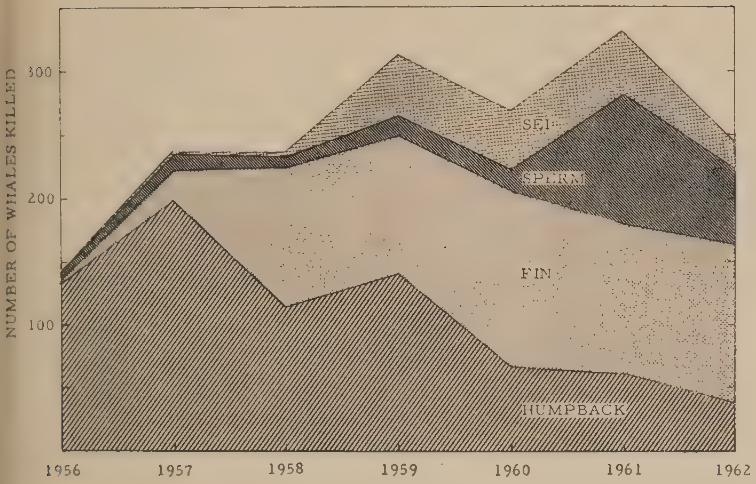
The catch of whales at the California stations has fluctuated ove the past 7 seasons. There is a general upward trend (Fig. 1), but th average number of whales killed annually by each boat may be de clining (Fig. 2). Analysis is difficult, because six species—especiall fin, sei, humpback, and sperm—contribute to the total. Severa factors besides the relative numbers of each species influence th catch composition, such as the relative ease of capture of the diffe ent species, and their average size and value, etc. Population trend from year to year are obscured by differences in the number of day of rough weather, and by variations in the movements of each spe cies due to variations in the abundance of the preferred food specie which are influenced by changes in oceanographic conditions. De spite these complications, when the data in Figures 1 and 2 ar analyzed against the background of other factors, several trends ar apparent.

Humpback whales constituted 92 per cent of the catch in 1956, an have declined steadily to 16 per cent in 1962. Humpbacks are fairl large, heavy-bodied whales, and are high in meat yield. They ar primarily a coastal species, and are relatively slow and easy to cap ture. Their preferred food is anchovies (*Engraulis mordax*). I 1956, large numbers of humpback whales could be found within 5

TABLE 2. PRODUCTION OF MEAT, MEAL, AND OIL BY THE CALIFORNIA WHALING STATIONS, 1956-62

[Quantities in metric tons; values in thousands of U. S. dollars]

Season	Meat Quantity	 Value	Meal Quantity	 Value	Whale oil Quantity	 Value	Sperm oil Quantity	 Value	Tot valu
1956	614	102	697	92	941	166	39	7	36
1957	816	160	1,132	203	1,397	196	90	18	57
1958	1,612	319	1,747	269	1,409	213	41	6	80
1959	1,690	347	1,708	263	1,697	253	78	12	87
1960	1,821	363	1,350	135	1,367	165	77	9	67
1961	2,245	397	1,490	201	1,255	179	302	61	88
1962	1,952	367	1,304	160	923	120	241	57	70



igure 1. Variation in the catch of the four most important species of whales at the California shore stations from 1956 to 1962.

ilometers (30 miles) of the Golden Gate, so the catcher boats rarely entured beyond the Farallon Islands. Today, few are seen here.

With the disappearance of the humpbacks, the catcher boats unted farther to sea. Finback whales, second in size only to blue hales, are common in the waters 60 kilometers (35 miles) and more ffshore. They feed chiefly on adult krill (*Euphausia pacifica*). Fin hales are more valuable than humpbacks, but their occurrence is ess regular and they are swifter and harder to catch. The weather s more often bad offshore, and the longer tows reduce the time vailable for hunting. These factors make it more urgent to get the arcasses back to the plant while the meat is still fresh. Since 1958, in whales have been the most important species in the catch. There s no indication that the stock is declining.

Sei whales, like fin whales, are usually found far offshore. They re considerably smaller than fin whales, though a sei whale yields nuch more meat than a young fin whale of equal length. Sei whales re present in California waters from July to October. They feed on mmature krill, anchovies, sauries (*Cololabis saira*), sardines (*Sarlinops sagax*) and copepods (*Calanus sp.*). Probably because of heir more varied diet, they often remain in an area when lack of eed causes fin whales to leave. With the shift in hunting emphasis rom humpback to fin whales, the sei whale catch has correspondingy increased. The sei whale population may be underexploited.

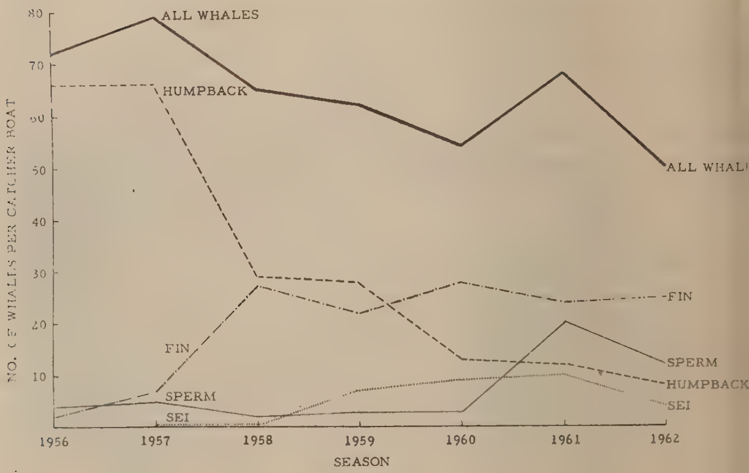


Figure 2. Variations in the total number of whales, and in the number of the four mo
important species, caught per boat at the California shore stations from 1956 to 1962.

Sperm whales were largely neglected during the first 5 years
modern California whaling, because there is little demand for the
black, oily meat. In 1961, however, sperm whales were more abu
dant than previously, seemingly because of a greater abundance
the large squid, *Moroteuthis robusta*, their most important foo
Female sperm whales usually remain in warmer waters, but sever
schools appeared off the California coast that year. Prices f
sperm oil were high, and there was an increased market for sper
whale meat. The two stations killed over one hundred sperms th
year, and in 1962 the catch of sperms remained high. In this polyg
nous species, few females exceed the legal minimum size of 10.7
(35 ft.), while males may grow to 17 m. (56 ft.); therefore the cat
is largely males. For this reason, local whaling can have little e
fect on the breeding potential of the stock.

Blue whales are the largest of whales. A few usually appear o
California in late September and October. They feed exclusively o
krill. Only in 1958 were they numerous enough to demand the excl
sive attention of the whalers for about 2 weeks.

Giant bottlenose whales, the largest of the beaked whales, are fr
quently seen. They are barely large enough, however, to be wort
capturing and are taken only when other species are not availab
For commercial purposes their meat and oil is considered the sam
as that of sperm whales.

THE U. S. WHALE RESEARCH PROGRAM

In 1958 the Marine Mammal Biological Laboratory of the U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, located in Seattle, Washington, initiated a research program on the commercially important species of whales. Prior to this, the Service's whale research centered primarily on the protected gray whale. Studies of the gray whale have continued, and studies of the bowhead whale in Arctic Alaska are also underway. Most of the research effort is now devoted to the commercial species. This is the only aspect of the present program I will discuss. The objectives of the research are to provide the biological facts necessary for sound management. We must answer the following broad questions: (1) What is the basic life history of each species—especially, its breeding habits and reproductive rate, its age at sexual maturity, its food habits, its parasites, and diseases? (2) What are the geographical limits of each particular stock, what are its migration routes, and to what extent does it intermingle with neighboring stocks? (3) What is the size of each stock, what are its population parameters, and what is its maximum sustainable yield?

The answers to these questions are difficult to get, because cetaceans are large, wide ranging, and elusive, and ships of adequate size to pursue them are expensive to operate. Much of our knowledge must be based on indirect evidence rather than on direct observations. We have four methods for obtaining data on the larger whales: (1) examination of the animals killed in commercial operations; (2) analysis of the statistics of the commercial catches. (3) data from the recovery of marked whales; and (4) observations of live animals at sea. Unfortunately, the larger whales cannot be kept in captivity, though some of the smaller species of cetaceans have been studied in oceanaria. Bottlenose dolphins have been maintained through several generations at Marineland, Florida, and have provided data which are useful in interpreting life history data on the larger species. To date, our research program has concentrated on the first of these approaches.

Since the 1959 season, we have examined the majority of whales taken by the two California stations. Routinely, the ear plugs are collected for age determination, and the ovaries, uterus, fetuses, mammary glands, and testes are examined to determine the reproductive status of the animals. Data on stomach contents, blubber thickness, ectoparasites, endoparasites, and extent of fusion of the vertebral epiphyses are recorded. These have provided a basic framework of life history data on the species and stocks which our stations are harvesting. Compared with the extensive data gathere by whale biologists in other parts of the world—particularly th Antarctic and the western North Pacific—it has revealed man similarities, as well as some significant differences. It also provide direct evidence on age composition of the catch.

Certain morphological and physiological features of whales observable at the stations—such as size at maturity, body proportions blood types, and frequency distribution of color phases, have provided evidence which suggests that the North Pacific populations o each species may be divided into several discrete stocks. Nevertheless, marking large numbers of whales is the only way to obtai direct evidence on their migrations, and the degree of interminglin between populations inhabiting different geographical areas. Th standard whale mark, developed 30 years ago by the British Discovery Investigations, has proved quite successful. Designed to b fired from a 12-gauge, open-bore shotgun, it consists of a stainles steel tube 23 cm. long, with a lead point. The mark is fired into th epaxial muscles of the whale's back. Some marks have been recovered in good condition after 25 years. Biologists of the Japanes Whales Research Institute initiated an extensive whale marketin program in the North Pacific in 1949. To date they have effectivel marked 3,443 whales of seven species; 249 have been recovered Soviet biologists have effectively marked about 500 whales; data o recoveries of Soviet marks are not available. The Japanese an Soviet marking in the North Pacific has been done exclusivel west of the 180th meridian, except for some Japanese marking in th eastern Aleutian and Kodiak area. From these data a broad picture of the patterns of movement is beginning to emerge (Fujino 1960). Unfortunately, it is only half a picture, for in the easter North Pacific only 36 whales have been effectively marked—20 b Canada and 16 by the United States. None of these has been recovered, but one Japanese mark has been recovered off Vancouve Island.

The long-distance movements of whales, revealed by markin programs, have shown the need for international cooperation in whal research. Research in the North Pacific has until now been conducted independently by the Japanese, Soviet, Canadian, and U S. Governments. An important step was taken by the Internationa Whaling Commission at its 14th Annual Meeting in London in Jun 1962. The Commission was alarmed about the prospects for Nort Pacific whale stocks, now threatened with increased exploitation. A the suggestion of Remington Kellogg, the U. S. Commissioner, th Commission appointed a committee consisting of one biologist fro ach of the four nations concerned—Canada, Japan, United States, and U. S. S. R. They instructed the committee to coordinate and review past and future research efforts in the North Pacific, and to advise the Commission on necessary management regulations.

At our first Committee meeting, a comprehensive review of whale marking accentuated the urgency of undertaking large-scale markings in the eastern North Pacific, particularly on the wintering grounds in the southeast. For several years, the U. S. Bureau of Commercial Fisheries has had plans for such a program. We made the first exploratory whale marking cruise in the waters off southern California and Baja California in November 1962, and will put in operation a realistic marking program as soon as possible.

Perhaps we have learned something from the tragic decline of the Antarctic whaling industry. Token regulations, tailored to suit the short-term convenience of the industry, will not save the whales, and when the whales are gone the industry will die with them. The industry and the governments involved are at last beginning to realize—we hope not too late—that each species and each stock of whales must be assessed and managed individually, that many more facts must be known before these assessments can be made, and that it is going to cost a lot of money to get these facts. Fortunately, a good start has been made by the Japanese and Soviet whale research organizations. If the other nations whaling in the North Pacific will cooperate in an adequate research program, there is still time to show that we can manage whale stocks on a sustained yield basis. We must decide soon whether we want those who come after us to suffer from our prodigality or to profit from our wisdom

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DISCUSSION

MR. IMES: In view of the fact that both the United States and Canada take a very low percentage of the total take of whales in the north Pacific, are they not in a rather awkward position to negotiate with Japan and Russia on some conservation methods?

MR. KENYON: Of course, I am not the whale man, and I can only speak in generalities. We don't, of course, know what our future needs might be, and since the high seas' resources are available to all nations of the north Pacific, we must consider we are to undertake the most thoughtful negotiation for conservation of these wide-ranging marine resources so that our future needs would not be jeopardized at any time.

Reprinted from Norsk Hvalfangst-Tidende 1963, No. 6 p. 153-160

he Whale Marking Cruise of the *Sioux City* off California and Baja California

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Biological Laboratory, Seattle 15, Washington

The Whale Marking Cruise of the *Sioux City* off California and Baja California

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Introduction.

The U.S. Fish and Wildlife Service, Bureau of mmercial Fisheries, as part of its whale research ogram, chartered the whale catcher *Sioux City* m the Golden Gate Fishing Company of Richond, California, for a cruise in the waters off uthern California and northern Baja California m 12 November to 1 December 1962.

The *Sioux City* is 41 m. long, has a gross tonge (metric) of 179, a cruising speed of 22 km/hr., d a range of over 8,000 km.

The purpose of the cruise was: (1) to obtain ta on the distribution and abundance of whales d other marine mammals; (2) to locate areas ere whales occur in sufficiently large numbers ring the winter season to warrant a more exnsive marking program in future years; and (3) mark as many whales as possible.

The crew of the *Sioux City* consisted of Harold Ridle, Captain and Engineer; Lloyd J. Newton aptain of the catcher boat *Lynnann);* and Robert Young. Robert Casebeer, Superintendent of the olden Gate whaling station, was aboard during e first week of the cruise. U.S. Fish and Wildlife rvice personnel were myself and Thomas J. cIntyre, a biological aid.

The whale marks and marking guns were anufactured by Holland and Holland, Ltd. The marks are of the same type as those used by the National Institute of Oceanography, being constructed of a stainless steel tube 23 cm. long, and 1.6 cm. in diameter, with a conical lead point 3.8 cm. long, the flattened tip of which is 5 mm. in diameter. The marks were inscribed as follows:

NOTIFY U.S. FISH AND WILDLIFE SERVICE
U.S. 27 U.S.27
SEATTLE. WASHINGTON. U.S.A.

They were serially numbered beginning with «U.S. 1.» The guns are 12-gauge, open-bore shotguns with rifle sights.

A continuous watch for marine mammals was maintained on the bridge from dawn (0700) until dusk (1700) every day, except on 29 and 30 November when heavy seas greatly reduced visibility.

Itinerary.

The course of the vessel is plotted on the accompanying map (fig. 1). Each day's run is briefly outlined below. North of 33° N. latitude, rough weather prevented us from getting as far offshore as we had planned, so that coverage in that area was very poor.

12 November. — We departed from the Golden

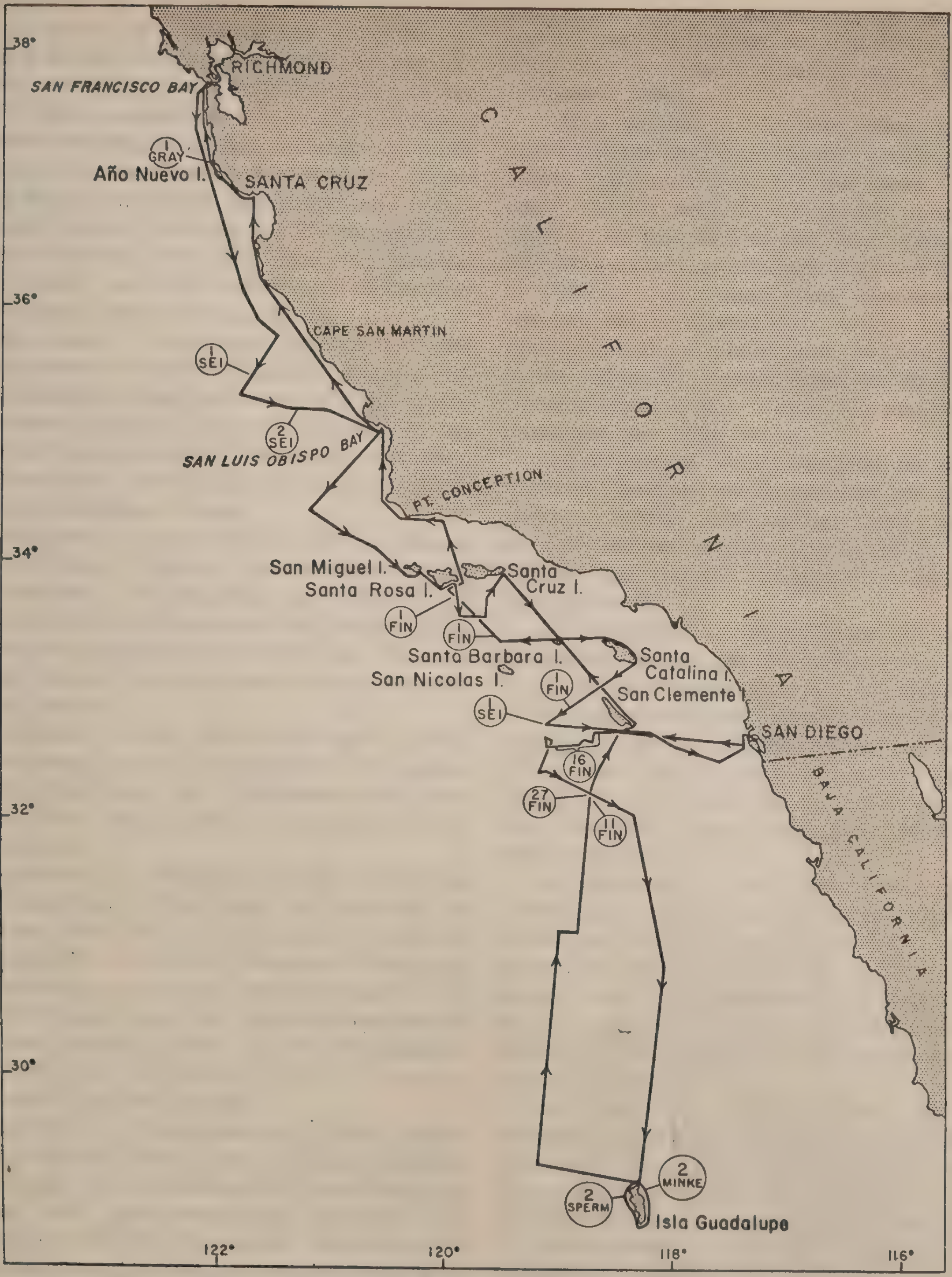
38°
36°
34°
32°
30°
122°
120°
118°
116°
RICHMOND
SAN FRANCISCO BAY
1 GRAY
Año Nuevo I.
SANTA CRUZ
C A L I F O R N I A
CAPE SAN MARTIN
1 SEI
2 SEI
SAN LUIS OBISPO BAY
PT. CONCEPTION
San Miguel I.
Santa Rosa I.
Santa Cruz I.
1 FIN
1 FIN
Santa Barbara I.
San Nicolas I.
1 FIN
Santa Catalina I.
San Clemente I.
1 SEI
SAN DIEGO
BAJA CALIFORNIA
16 FIN
27 FIN
11 FIN
2 MINKE
2 SPERM
Isla Guadalupe

Figure 1. — Course of the *Sioux City*, showing the location of all large whales sighted.

e Fishing Company dock at Point San Pablo, mmond, California, at 1610. We passed under the den Gate bridge at 1705, and headed south down coast, running all night.

13 November. — At 0715 we were 26 kilometers Cape San Martin. We headed southwest to the)-meter depth contour, and then turned east. anchored in San Luis Obispo Bay at 1815. There was a heavy swell, and a northwest wind of about 20 km/hr., all day.

14 November. — We raised the anchor at 0730 and headed southwest. At 1300 we reached the 2000-meter contour, and then turned southeast. We dropped anchor off the south side of San Miguel Island at 2000. The heavy swells and northwest wind continued.

15 November. — We left our anchorage at 0830, ded southeast, and followed the south side of ta Rosa Island. Reaching the southeast end of island, we turned south and continued to the meter depth contour at the southern edge of shallow bank which extends southeast of Santa a Island. We then headed east into the deeper 50 m.) Santa Cruz Basin, then north and north- towards Santa Cruz Island. We anchored in iggler's Cove at 1630. The wind was blowing ut 20 km/hr., and the water was moderately gh, except in the lee of the islands.

16 November. — We pulled anchor and left ta Cruz Island at 0730. We made a straight run Santa Barbara Island, anchored off the south- side from 1200 to 1245, then ran east to the th end of Santa Catalina Island and ran down northeast shore, anchoring off Avalon at 1700. weather continued rough.

17 November. — We left Avalon at 0700, round- the south end of Santa Catalina Island, and ded southwest. The weather was calm in the rning, but the wind increased in intensity, and 600 we were forced to turn back east. We stop- the engines at 2100, southeast of San Clemente nd, and drifted.

18 November. — We got under way at 0630, ded southeast, and then northeast. We docked an Diego Harbor at 1400. The weather was calm ore, but still rough offshore, according to the ther reports.

19 November. — We spent the day obtaining essary supplies in San Diego. We departed at 0, and ran west for the remainder of the night.

20 November. — At 0700 we were off the south of San Clemente Island. We encountered fin ales a few hours later, and spent several hours suing and marking them. At 1730 we dropped anchor in 38 m. over Tanner Bank. The weather very calm and clear all day.

21 November. — We started up at 0650, headed th over Cortes Bank, and southeast towards tymile Bank. We encountered large numbers of whales, and spent much time pursuing and rking them. At 1700 we stopped the engines 33 meters northwest of Sixtymile Bank and drifted. weather was good with a light breeze and oth, gentle swells.

22 November. — We got underway at 0645, ded southeast toward Sixtymile Bank, and then thwards. No whales were seen, so we continued ning until 2030 and then drifted at 30°16' N., °07' W. The weather continued calm.

23 November. — We started the engines at 0700 continued running to the south. We reached ta del Norte on Isla Guadalupe at 1430, and closely followed the east side of the Island. We anchored close off the east shore at 29°00' N., at about 1700. The weather continued calm, with a light northwest breeze.

24 November. — At 0700, Newton, McIntyre, and I put the skiff over the side and began to work slowly northward just off the rocks, in order to count the fur seals. The outboard motor failed at 0700, so we returned to the *Sioux City* which was following us farther offshore. We fixed the outboard by 0930 and continued along the shore until we reached the northeast cove, where we landed to photograph the elephant seals. At 1300 we returned to the *Sioux City*, headed down the west shore, and circumnavigated the island. We anchored in the northeast cove after dark.

25 November. — We weighed anchor at 0830, rounded Punta del Norte, ran west for several hours and then turned north. We ran until midnight and then drifted; our position was 31°14' N., 119°00' W. The sea was choppy, and the wind was 20 km/hr. from the west.

26 November. — By 0600 we had drifted east to 118°50' W. We headed north and encountered fin whales in the position we had found them on 21 November; we spent several hours chasing and marking them. At 1800 we stopped the engines and drifted 5 km. off the southwest end of San Clemente Island. The wind was blowing about 20 km/hr. from the northwest. There were large swells, but not much white water.

27 November. — We got underway at 0645 and headed west. We soon encountered a school of pilot whales and collected one. By the time we had it aboard the wind had picked up to 25 km/hr., so we decided to go up the lee side of San Clemente Island. We then headed for Santa Barbara Island, and ran into fog. We anchored in the southeast cove of Santa Barbara Island at 1450.

28 November. — We weighed anchor at 0630 and ran west towards San Nicolas, but the wind became so strong that we turned towards Santa Rosa Island instead, where we anchored at 1500. The wind became much stronger in the evening.

29 November. — We raised the anchor and left Santa Rosa Island at 0700. We went through Santa Cruz Channel, crossed Santa Barbara Channel, and followed the coast closely around Point Conception, finally anchoring in San Luis Obispo Bay at 2000. The weather was extremely rough, with winds exceeding 60 km/hr. off Point Conception.

30 November. — We left San Luis Obispo Bay at 0830, and closely followed the coast north. We anchored off Santa Cruz at 2130. Heavy swells and west winds of 60 km/hr. continued. The vessel rolled as much as 62° at times.

1 *December.* — We pulled in the anchor and Santa Cruz at 0630 and continued north along coast. We entered San Francisco Bay and tied at the Richmond Yacht Harbor at 1500. The ther was fairly good close inshore, but still gh offshore.

Marine Mammal Observations.

Ten species of cetaceans and six species of pineds were encountered during the cruise. The es and positions of each sighting, and the number of animals in each group, are summarized in the following account. In addition to the identified sightings, nine unidentified dolphins or porpoises, and one unidentified small whale were observed.

Balaenoptera physalus. Fin whale. Fin whales were encountered in numbers only in the waters southwest of San Clemente Island. A few scattered animals were seen elsewhere. Much of the time the weather was too rough to get far enough offshore where fin whales might be expected. About 57 fin whales, in 23 pods, were sighted:

Date	Position	Number	Remarks
November	33°50'N., 119°59'W.	1	Heading south; mark No. 3 fired.
»	32°55'N., 118°56'W.	1	Heading west.
»	32°46'N., 118°39'W.	4	Three together, one alone. Heading S.S.E. Marks No. 4 and 5 fired.
»	32°46'N., 118°42'W.	6	One group of four, another of two. Heading S.S.E. Marks No. 6 — 12 fired.
»	32°40'N., 118°48'W.	2	Heading S.S.W. Marks No. 13 — 15 fired.
»	32°38'N., 118°56'W.	3	Heading S.S.W. Marks No. 16 and 17 fired.
»	32°37'N., 119°01'W.	1	
»	32°17'N., 118°45'W.	25	In groups of 5, 4, 3, 3, 2, 2, 2, 1, and 1. Moving in a general westerly direction. Marks No. 18 — 21 fired.
»	32°14'N., 118°37'W.	2	Mark No. 23 fired.
»	32°17'N., 118°45'W.	11	In groups of 3, 3, 1, 1, 1, 1, and 1. Marks No. 24 — 26 fired.
»	33°34'N., 119°42'W.	1	

Balaenoptera borealis. Sei Whale. Only four sei whales were seen:

Date	Position	Number	Remarks
November	35°30'N., 122°00'W.	1	Mark No. 1 fired.
»	35°18'N., 121°37'W.	2	Mark No. 2 fired.
»	32°49'N., 119°08'W.	1	

Balaenoptera acutorostrata. Minke Whale. Only two minke whales were identified:

Date	Position	Number	Remarks
November	29°09'N., 118°15'W.	2	In cove on NE side of Isla Guadalupe.

Eschrichtius gibbosus. Gray Whale. It was too ly to expect many migrating gray whales in thern Californian waters, and we were usually too far offshore to find them, as they are a coastal species. One was encountered off Pigeon Point:

Date	Position	Number	Remarks
December	37°12'N., 122°26'W.	1	Mark No. 27 fired.

Physeter macrocephalus. Sperm Whale. Only two sperm whales were sighted:

Date	Position	Number	Remarks
November	29°08'N., 118°24'W.	1	Large animal.
»	29°08'N., 118°23'W.	1	Large — ca. 17 m. long; mark No. 22 fired.

Phocoenoides dalli. White-flanked Porpoise. ite-flanked porpoises were the third most numerous cetacean observed. Nine schools, totaling about 64 animals, were sighted, all north of 33°N. latitude:

ate	Position	Number	Remarks
vember	35°05'N., 120°49'W.	4	
»	35°03'N., 120°52'W.	ca. 12	
»	34°57'N., 120°57'W.	7	
»	34°53'N., 121°03'W.	4	
»	34°48'N., 121°07'W.	1	
»	33°29'N., 118°52'W.	8	
»	33°13'N., 118°41'W.	3	
»	33°30'N., 119°13'W.	ca. 15	
»	33°31'N., 119°38'W.	ca. 10	

Globicephala macrorhyncha. Short-finned Pilot e. Pilot whales were encountered only in the waters around San Clemente Island:

ate	Position	Number	Remarks
vember	33°07'N., 118°41'W.	ca. 16	Including 3 or 4 old males.
»	32°46'N., 118°24'W.	ca. 24	One group of 4, another of about 20. One animal collected.
»	32°55'N., 118°26'W.	ca. 20	

Lagenorhynchus obliquidens. Striped or Spot- Dolphin. This species was the second most abundant cetacean. About 113 individuals in 6 schools were sighted:

ate	Position	Number	Remarks
vember	35°16'N., 121°08'W.	ca. 75	
»	34°23'N., 121°14'W.	6	
»	34°21'N., 121°11'W.	5	
»	34°21'N., 121°10'W.	7	
»	34°13'N., 120°43'W.	7	
»	32°40'N., 119°05'W.	13	One group of four, another of nine.

Tursiops truncatus. Bottlenose Dolphin. Bottle- dolphins were found only close to the east shore of Isla Guadalupe:

ate	Position	Number	Remarks
vember	29°03'N., 118°13'W.	8	Ran ahead of bow, uttering audible whistles as streams of air bubbles escaped from blowhole.

Delphinus delphis. Saddleback Dolphin. These hins were the most numerous cetacean. Eleven schools, containing about 320 individuals, were sighted. One specimen was collected:

Date	Position	Number	Remarks
ovember	32°40'N., 118°00'W.	ca. 20	One animal collected.
»	32°37'N., 117°56'W.	ca. 30	
»	32°36'N., 117°55'W.	ca. 12	
»	32°35'N., 117°54'W.	ca. 5	
»	32°45'N., 118°42'W.	ca. 150	
»	32°40'N., 118°48'W.	3	
»	31°47'N., 118°18'W.	4	
»	31°43'N., 118°18'W.	ca. 15	
»	31°30'N., 118°14'W.	1	
»	31°18'N., 118°50'W.	ca. 30	
»	33°17'N., 118°48'W.	ca. 50	

Zalophus californianus. Black Sea Lion. We ed most of the islands too far offshore to observe sea lions, but this species was observed hauled out on the following islands:

Date	Island	Number	Remarks
ovember	Santa Barbara Island (SE side)	ca. 250	
»	»	ca. 300	
»	Santa Catalina Island (S. end)	ca. 700	
»	Isla de Afuera (off S. end of Isla Guadalupe)	ca. 30	
ecember	Año Nuevo Island	ca. 100	

Over 50 sea lions were observed at sea:

Date	Position	Number	Remarks
November	33°40'N., 119°41'W.	1	
»	33°30'N., 119°02'W.	2	
»	33°15'N., 118°22'W.	1	
»	32°38'N., 119°08'W.	18	
»	32°42'N., 119°08'W.	15+	Vessel anchored in 38 m over Tanner Bank; sea lions feeding on fish attracted to light after dark.
»	32°41'N., 119°06'W.	1	
»	32°40'N., 119°05'W.	1	
»	32°40'N., 119°05'W.	5	
»	32°26'N., 119°13'W.	1	
»	32°23'N., 119°13'W.	1	
»	32°23'N., 119°08'W.	1	
»	33°30'N., 119°11'W.	2	
»	35°07'N., 120°47'W.	1	On buoy outside San Luis Obispo Bay.

Eumetopias jubata. Northern Sea Lion. This species was found hauled out at only one locality:

Date	Island	Number	Remarks
December	Año Nuevo Island	ca. 500	Mostly segregated from Zalophus.

Arctocephalus philippii. Guadalupe Fur Seal. is rare species was found hauled out only on the t side of Isla Guadalupe, between 29°00' and 29°05' N. latitude (both sightings refer to the same group of animals):

Date	Island	Number	Remarks
November	Isla Guadalupe	ca. 35	Count made from catcher boat.
»	»	67	Count made from skiff; one pup with mother.

None were identified at sea.

Callorhinus ursinus. Northern Fur Seal. It was early in the winter for large numbers of northern fur seals to be in the area; only one was sighted at sea:

Date	Position	Number	Remarks
November	32°46'N., 118°24'W.	1	Small.

Mirounga angustirostris. Northern Elephant al. Elephant seals were found hauled out only at Guadalupe Island:

Date	Island	Number	Remarks
25 November	Isla Guadalupe	500	East side, in cove south of Pilot Rock.
24 »	»	700	West side between Roca Elefante and Punta del Vapor.

One was observed at sea:

Date	Position	Number	Remarks
November	32°19'N., 118°51'W.	1	

Phoca vitulina. Harbor Seal. Harbor seals were seen hauled out at only one place:

Date	Island	Numer	Remarks
November	Rocks under Richmond - San Rafael bridge in San Francisco Bay.	15	Site of regular summer hauling ground.

None were observed at sea.

Whale Marking.

Twenty-seven whale marks were fired — 2 at whales, 1 at a sperm whale, 1 at a gray whale, 23 at fin whales. The results of these shots were ollows:

Hit	17
Hit, mark protruding	1
Possible hit	3
Ricochet	2
Miss	4

Those shots recorded as «possible hits» struck the water before touching the whales, which in each case reacted violently, indicating that they had been hit, but it is not certain that the mark penetrated. Sixteen whales — fifteen fins and one sperm — were effectively marked; one of the fins was hit twice. In addition, two sei and one fin were recorded as «possible hits».

The details of the marks fired are recorded in table 1.

Table 1. — Details of marks fired, 1962.

Mark umber	Date	Position		Species	Est. length (ft.)	Result of shot
		Latitude N.	Longitude W.			
S- 1	13 Nov.	35°30'	122°00'	Sei	40—42	Possible hit
S- 2	—	35°18'	121°36'	Sei	50	Possible hit
S- 3	15 Nov.	33°50'	119°59'	Fin	60	Hit
S- 4	20 Nov.	32°46'	118°35'	Fin	60	Ricochet
S- 5	—	»	»			Possible hit
S- 6	—	32°46'	118°42'	Fin	60+	Hit
S- 7	—	»	»	Fin	60+	Hit, protruding
S- 8	—	»	»	Fin	60+	Hit
S- 9	—	»	»	Fin	65+	Hit
S-10	—	»	»			Hit
S-11	—	»	»	Fin	60+	Miss
S-12	—	»	»	Fin	60+	Hit
S-13	—	32°40'	118°48'	Fin	65+	Miss
S-14	—	»	»			Hit
S-15	—	»	»	Fin	65+	Hit
S-16	—	32°38'	118°56'	Fin	65	Hit
S-17	—	»	»	Fin	68	Hit
S-18	21 Nov.	32°17'	118°45'	Fin	65	Hit
S-19	—	»	»	Fin	65	Hit
S-20	—	»	»	Fin	55	Ricochet
S-21	—	»	»	Fin	55—58	Hit
S-22	24 Nov.	29°08'	118°23'	Sperm	55	Hit
S-23	21 Nov.	32°14'	118°37'	Fin	70	Miss
S-24	26 Nov.	32°17'	118°45'	Fin	58	Hit
-25	—	»	»	Fin	66	Hit
S-26	—	»	»	Fin	60	Hit
S-27	1 Dec.	37°12'	122°26'	Gray	45	Miss

Discussion.

The short cruise was hampered by rough her, which prevented us from getting as far hore as we had hoped. No conclusions can yet nade concerning the overall distribution and ements of the larger whales, but the observa- did suggest certain possibilities for future in- gation.

Most of the fin whales were observed beyond Clemente Island. Only two were seen east of a drawn from San Miguel Island to San Nicolas d and to San Clemente Island. Therefore the migration path must lie to the west of these islands. The fin whales observed between San Clemente Island and Tanner and Cortes Banks were mostly moving in a general southerly direction. Those encountered about 50 kilometers farther south, however, seemed to be moving in a more westerly direction. Not a single fin whale was observed south of that point all the way to Isla Guadalupe. Captains Ridle and Newton have, in the previous two winters, made two straight runs from Isla Cedros, just off Punta Eugenia, to San Clemente Island, and they saw no fin whales or whales of any kind. All these facts indicate that the fin whales do not continue to move south-southeast, parallel to the coastline, but turn to the west and

er head far offshore, or else remain in this gen-
latitude to the west of the Channel Islands.

One fin whale was observed swimming steadily
south at a point 9 kilometers south of the east
of Santa Rosa Island. It doubtless had come
ugh the Santa Cruz Channel, and therefore it
t have turned east into the Santa Barbara
nnel after passing Point Conception on its
hward migration. Another animal seen near
13 days later would suggest that this same
e may be followed regularly by a small number
n whales.

The only sei whales observed were far offshore.
t sei whales have left the whaling grounds off
Francisco (38° N. latitude) by early October.
movement of sei whales through the area of the
se had doubtless passed its peak. Therefore they
st spend the winter either farther to the south,
her at sea, or both.

It was perhaps significant that not a single
npback whale was seen, since they are predomi-
tly coastal animals; they must move much
her south during the winter. We have received
orts of humpbacks in the coastal waters from
o de San Lucas south to Mazatlan and the Islas
illa Gigedo.

The scarcity of sperm whales was probably due
hance, as other observations have revealed that
y are thinly distributed off the entire coast of
ifornia during the winter.

Summary.

The whale catcher *Sioux City*, on charter to the U.S. Bureau of Commercial Fisheries from the Golden Gate Fishing Company of Richmond, California, made a whale-marking cruise in the waters off southern California and northern Baja California, from San Francisco Bay (38° N. lat.) south to Isla Guadalupe (29° N. lat.), between 12 November and 1 December 1962. Rough weather prevented surveying much of the most promising offshore area.

Fifty-seven fin whales *(Balaenoptera physalus)*, in twenty-three pods, were sighted, mostly southwest of San Clemente Island. Four sei whales *(B. borealis)* and two sperm whales *(Physeter macrocephalus)* were seen. Other cetaceans sighted were *Balaenoptera acutorostrata* (2), *Eschrichtius gibbosus* (1), *Phocoeniodes dalli* (ca. 64), *Globicephala macrorhyncha* (ca. 60), *Lagenorhynchus obliquidens* (ca. 113), *Tursiops truncatus* (8) and *Delphinus delphis* (ca. 320). The following pinnipeds were observed: *Zalophus californianus, Eumetopias jubata, Arctocephalus philippii, Callorhinus ursinus, Mirounga angustirostris,* and *Phoca vitulina.*

Twenty-seven whale marks were fired. Sixteen whales — 15 fins and 1 sperm — were effectively marked.

The observations indicate that most migrating fin whales pass to the west of the Channel Islands. They do not continue to travel parallel to the coast south of those islands, but apparently head farther out to sea in a westerly direction.

Reprinted from Norsk Hvalfangst-
Tidende 1963, No. 7 p. 181-187

Progress Report on Biological Studies of the Larger Cetacea in the Waters off California

By Dale W. Rice

rogress Report on Biological Studies of the larger Cetacea in the Waters off California

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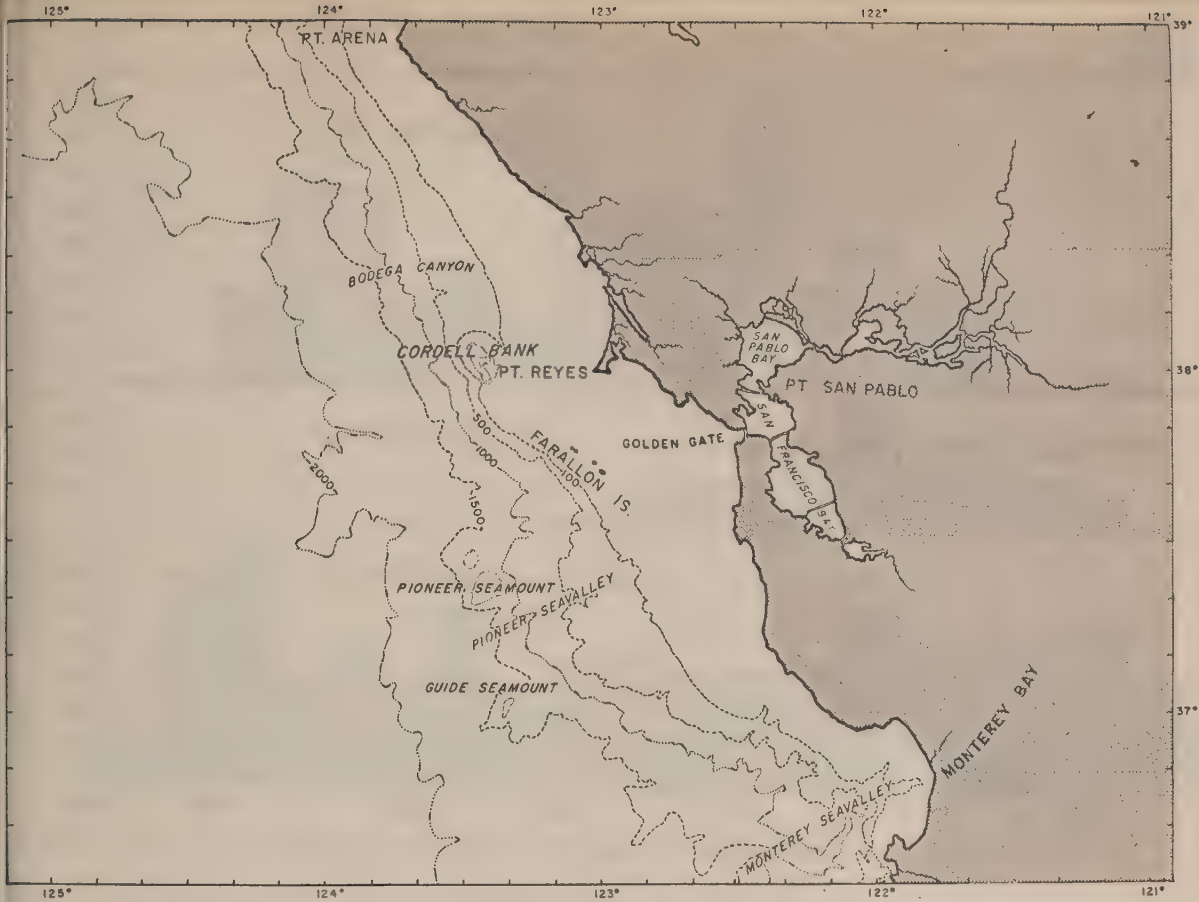
ABSTRACT: This report is a preliminary synopsis certain features of the life history and ecology the blue whale *(Balaenoptera musculus)*, fin hale *(B. physalus)*, sei whale *(B. borealis)* hump- ick whale *(Megaptera novaeangliae)*, gray whale *Eschrichtius gibbosus)*, sperm whale *(Physeter acrocephalus)*, and giant bottlenose whale *(Ber- dius bairdi)*, in the waters off central California, ased on the examination of 737 whales taken by vo shore stations from 1959 through 1962, and on e catch statistics for 1,815 whales taken by the ations from 1956 through 1962.

Introduction.

In 1959, the Marine Mammal Biological Labor- ory of the U.S. Fish and Wildlife Service, Bureau Commercial Fisheries, initiated a research pro- am on the larger species of whales which occur f the Pacific Coast of the United States. For ad- inistrative purposes, this program is divided into o projects: (1) Studies on the species that are pro- cted from commercial utilization by the Interna- onal Convention for the Regulation of Whaling, d (2) studies on the commercially important spe- es. In the former category are included studies on e California gray whale *Eschrichtius gibbosus*, in- uding counts of the southward migration (Rice, 61b) and the examination of specimens taken der Special Scientific Permits; and studies on the bowhead whale *Balaena mysticetus* and aboriginal whaling methods in arctic Alaska. Under the second category are included studies on the whales taken by the two shore stations in Richmond, California; a marking program recently initiated in the waters off southern California and northern Baja California (Rice, 1963b); and observations at sea made from the catcher boats. During the past four seasons, primary emphasis has been placed on the examination of the whales in the commercial catch. The objectives were to determine the major features of the life history, ecology, and population dynamics of the whale stocks occurring in the waters off California. These studies are continuing, and a detailed report of the results is in preparation. Pending the publication of the complete report, the present preliminary report has been prepared to make available to workers in other parts of the world an abstract of the more important findings to date. This report summarizes only the life history and ecological data obtained at the whaling stations on the larger species of whales, including both the commercially utilized species and the California gray whale. No attempt is here made to summarize the data on population dynamics or on observations at sea; an analysis of that data will be included in the final report.

Seven species of large cetaceans (here defined as those species which attain a length of 10 m (33 ft) or more at sexual maturity) are found regularly in the waters off California:


125°
124°
123°
122°
121°
39°
38°
37°
PT. ARENA
BODEGA CANYON
CORDELL BANK
PT. REYES
SAN PABLO BAY
PT SAN PABLO
SAN FRANCISCO BAY
GOLDEN GATE
FARALLON IS.
500
1000
100
1500
2000
PIONEER SEAMOUNT
PIONEER SEAVALLEY
GUIDE SEAMOUNT
MONTEREY BAY
MONTEREY SEAVALLEY

igure 1. Chart of the whaling grounds off central California. Soundings in fathoms (1 fm = 1.829 m). Modified from U.S.
; and Geodetic Survey Chart No. 5021.

e whale *Balaenoptera musculus*
whale *Balaenoptera physalus*
whale *Balaenoptera borealis*
mpback whale *Megaptera novaeangliae*
ay whale *Eschrichtius gibbosus*
rm whale *Physeter macrocephalus*
nt bottlenose whale *Berardius bairdi*

ven have been included in this study. Six of
are taken commercially; the gray whale is
y protected. One other large species, the black
whale *Balaena glacialis*, was formerly an oc-
nal winter visitor to these waters. It is now
rare, and since these studies began only one
een sighted — in May 1959.

Study Area.

ese studies were made at the two shore stations
ted by the Del Monte Fishing Company and
olden Gate Fishing Company. Both are locat-
Point San Pablo, on San Francisco Bay, in the
of Richmond, California. An account of these
whaling operations has been presented elsewhere (Rice, 1963a), and need not be repreated here.

From 1956 through 1959, the season on baleen whales was open from 1 May to 30 October. From 1960 through 1962, it was open from 16 April to 15 October. The season on sperm whales was open from 1 April to 30 November. The gray whales were taken under Special Scientific Permits during February and March.

The two stations employ a total of five catcher boats. The catcher boats operate within a radius of 230 km (125 nautical miles) of the Golden Gate. The northern limit is just north of Point Arena (39°00' N. lat.); the southern limit is off Monterey Bay (36°30' N. lat.). The western limit is about 124°50' W. long.

Along this section of the coast (fig. 1) the continental shelf is 30 to 45 km wide. Cordell Bank and the Farallon Islands mark the outer edge of the shelf. The continental slope drops off steeply to the ocean floor, which lies at a depth of 2,700 to 4,000 meters. Several seamounts (Pioneer Seamount, Guide Seamount) rise from the slope, which is cut

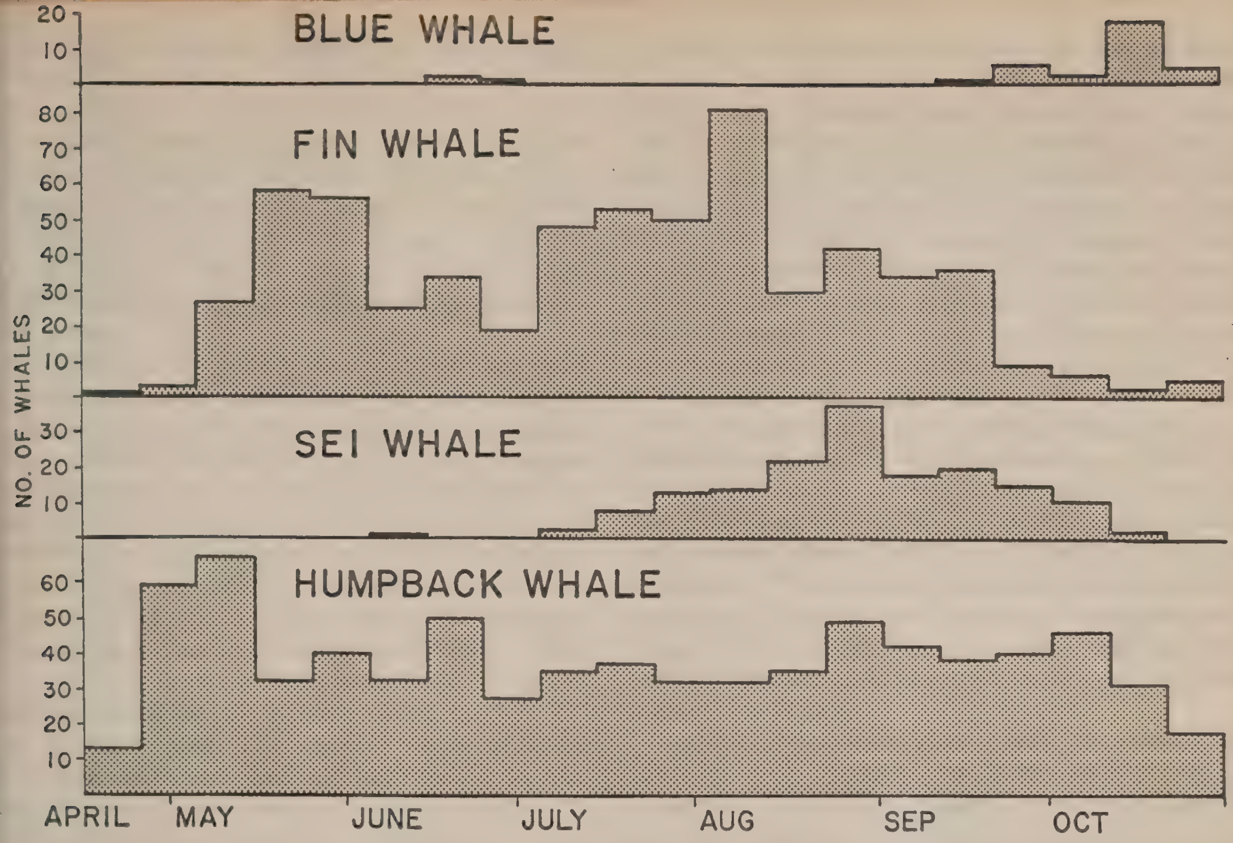


Figure 2. Catch of baleen whales, by 10-day periods, during the years 1956 to 1962.

several seavalleys (Bodega Canyon, Pioneer Sea- lley, Monterey Seavalley). The cool California rrent, with an annual temperature range of 11.9° 14.7° C, flows southward off the coast. There is tense upwelling from March to July.

Materials and Methods.

This report is based on the examination of 737 hales from 1959 to 1962, and on the catch statis- s for the 1,815 whales taken from 1956 to 1962. he numbers of each species that were taken and amined each season are presented in table 1.

In the whaling stations, the following data and ecimens were routinely collected: (1) total ngth; (2) species and numbers of ectoparasites d epizoites; (3) thickness of blubber on back, le, and belly; (4) condition and thickness of ammary glands, plus a representative series of istological specimens; (5) ear plugs from baleen hales, and teeth from a small series of sperm hales; (6) weight of ovaries, number of corpora picantia, weight and diameter of corpus luteum, d size and condition of Graafian follicles; (7) dia- neter of uterine cornua; (8) length and sex of fetus; (9) weight of testes, plus a series of histological specimens; (10) species and quantity of food in stomachs; (11) species and number of endoparasites in the stomach, intestine, liver, and kidneys; and (12) degree of fusion of vertebral epiphyses in the anterior thoracic region. It was not always possible to get complete data from every whale examined; this accounts for the discrepancies in the number of animals examined for different features.

The hypothesis that two ear plug laminations are formed each year is not supported by data recently obtained in the Antarctic from fin whales marked 25 years earlier (Ohsumi, 1962). These data are consistent with the hypothesis that only one lamination is formed per year. Until this is corroborated by the recovery of ear plugs from known-age whales, I prefer to express age simply in terms of number of laminations.

BLUE WHALE *(Balaenoptera musculus).*

Blue whales occur in local waters only in late September and October, except for a very few that have been found in June (fig. 2).

The stomachs of blue whales contained only the

mon krill *Euphausia pacifica.* One was empty; were nearly empty; the other six were full.

ıe meager data suggest that females attain .al maturity when they have accumulated 9 to ar plug laminations, at a length of 20.4 m (67 Females attain physical maturity when they accumulated 25 to 46 laminations, at a length 3.5 m (74 ft) to 18.9 m (82 ft). No data on age length at sexual or physical maturity are avail- for males.

ıe extrapolated conception date of the only s was December. Data from two old adult fe- es indicate that corpora albicantia are accumu- d at a rate of 0.42 to 0.50 per ear plug lamina- , following sexual maturity. One of three mature ales was pregnant; none were lactating.

ctoparasites and epizoites found on blue whales uded the whalesucker *Remilegia australis* on (44 %) of the nine whales (Rice and Caldwell, .), and the barnacle *Xenobalanus globicipitis* on (14 %) of seven whales examined. Lamprey *ıpetra tridentata* scars were noted on five (71 of seven whales. The baleen plates of three .les were examined, and all were found to har- the minute copepod *Balaenophilus unisetus.* On legs of the copepods from two of the whales large numbers of an undescribed chonotrich .te, which is normally found on cyamids (see w under Humpback Whale).

he only endoparasite was an acanthocephalan *bosoma* sp., found in the intestines of three (33 of the nine animals.

FIN WHALE *(Balaenoptera physalus).*

in whales are present in the waters off central fornia chiefly from early May to the middle of tember, with peaks of abundance from the dle of May to early June, and from mid-July to y September (fig. 2).

he stomachs (or intestines) of 261 fin whales tained recognizable food remains. The frequen- of occurrence of each food species was as fol- s: Adult krill *(Euphausia pacifica)* in 237 (90 f all occurrences); anchovies *(Engraulis mord-* in 26 (10 %). Of the 288 stomachs examined, (52 %) were full, 74 (26 %) were half full, and 22 %) were empty or nearly so.

exual maturity is attained when a mean num- of 10 (range: 9 to 15) ear plug laminations have accumulated, at a mean length of 18.6 m (61 in females, 17.5 m (57.5 ft) in males. Physical urity is reached when about 30 laminations e been accumulated, at a mean length of 20.9 m 6 ft) in females, 19.7 m (64.6 ft) in males.

The breeding season, based on the extrapolation of fetal growth curves, is September through March (and possibly June in one case), with a peak in November. Corpora albicantia are accumulated at a mean rate of 0.44 (95 % confidence interval: 0.37—0.51) per ear plug lamination, following sexual maturity. The observed pregnancy rate of adult females was 39 percent; however, the sample is biased, and the calculated true rate may be anywhere between 35 and 51 percent. Two females were simultaneously pregnant and lactating. Three cases of twin fetuses were observed.

Fin whales rarely carry ectoparasites. The only species found was *Penella balaenoptera,* which was present on only 5 (2 %) of 287 whales examined. The skin of almost all of the fin whales was moderately scarred from the bites of lampreys *Lampetra tridentata.* The nematode *Odontobius ceti,* and the copepod *Balaenophilus unisetus* were frequently found in the baleen film; the copepods sometimes carried chonotrich ciliates on their legs (see above under Blue Whale).

Endoparasites were also scarce. Nematodes *Anisakis* sp. were found in 19 (7 %) of 270 stomachs examined. The kidney worm *Crassicauda* sp. was found in 10 (62 %) of 16 kidneys carefully examined.

SEI WHALE *(Balaenoptera borealis).*

Sei whales are present chiefly from the middle of July to early October, with a peak of abundance in late August and early September (fig. 2).

In the stomachs (or intestines) of the 77 sei whales which contained recognizable food remains, the frequency of occurrence of each food species was as follows: Anchovies *(Engraulis mordax)* in 29 (36 % of all occurrences); sauries *(Cololabis saira)* in 8 (10 %); sardines *(Sardinops sagax)* in 1 (1 %); krill *(Euphausia pacifica),* mostly juvenile, in 40 (50 %); and copepods *(Calanus* sp.) in 2 (3 %). Of the 83 stomachs examined, 33 (40 %) were full, 15 (18 %) were half full, and 35 (42 %) were empty or nearly empty.

Sei whales attain sexual maturity when they have accumulated 10 to 14 ear plug laminations, at a mean length of 13.7 m (45 ft) for females, 12.8 m (42 ft) for males. They reach physical maturity after about 30 laminations have been accumulated, at a mean length of 14.7 m (48.2 ft) in females, 13.6 m (44.7 ft) in males.

The breeding season, as determined by extrapolations of fetal growth curves, is October to March, with a peak in November.Corpora albicantia are accumulated at a mean rate of 0.40 (95 % confidence interval: 0.31 — 0.50) per lamination, fol-

wing sexual maturity. The observed pregnancy te of adult females was 45 percent, but the true te may be anywhere between 34 and 50 percent. multiple pregnancies, and no cases of simul- neous pregnancy and lactation, were found.

Sei whales rarely carry ectoparasites. *Penella laenoptera* was found in 4 (5 %) of 80 animals amined. The sessile barnacle *Coronula reginae* curred on one (1 %) and *Xenobalanus globicipi-* was present on two (2 %). The whalesucker *emilegia australis* was observed on one (1 %) sei hale. All sei whales were heavily scarred with the tes of lampreys *Lampetra tridentata*. A film of atoms *Cocconeis* sp. was visible on only one (1 %) hale. The baleen plates frequently harbored *Ba- enophilus unisetus* and *Odontobius ceti*.

Sei whales are usually heavily parasitized intern- ly. Of 39 carefully examined, only 2 (5 %) were ee of endoparasites, and some were infested with many as four kinds. Liver flukes *Lecithodesmus* were present in nine (23 %). Small cestodes *etrabothrius* sp. occurred in the intestines of two %), and a larger, unidentified cestode (possibly *phyllobothrium*) in one (3 %). Nematodes *Anisa-* sp. were present in 42 (50 %) of 84 stomachs amined. The nematode *Crassicauda* was found in (8 %) of 13 whales whose kidneys were carefully amined. Two species of acanthocephalans *Bolbo- ma* spp. were present in the intestines of 27 (69) of 39 whales examined. Heavy infestations of er flukes and stomach worms sometimes result debility, and possibly mortality.

A unique pathological condition, causing pro- essive loss of the baleen plates, and their replace- nt by abnormal growth, was noted in 5 (6 %) of 88 whales examined (Rice, 1961a).

UMPBACK WHALE *(Megaptera novaeangliae)*.

Iumpback whales are present off the central Ca- rnia coast from the middle of March through ober (fig. 2).

The frequency of occurrence of food items in the machs (or intestines) of the 149 humpback ales which contained recognizable remains was follows: Anchovies *(Engraulis mordax)* in 98 % of all occurrences), and krill *(Euphausia pa- ca)* in 54 (36 %). Of 153 stomachs examined, (82 %) were full, 16 (10 %) were half full, and (8 %) were nearly or quite empty.

Iumpbacks attain sexual maturity when a mean nber of 10 (range: 8 to 14) ear plug laminations e been accumulated, at a mean length of 12.0 m .5 ft) for females, 11.7 m (38.5 ft) for males. y reach physical maturity when about 35 laminations have been acquired, at a mean length of 14.8 m (48.4 ft) for females, 13.6 m (44.6 ft) for males.

The breeding season, based on the extrapolation of fetal growth curves, is October through April, with a peak in December. Corpora albicantia are accumulated at a rate of 0.40 (95 % confidence interval: 0.31 — 0.50) per ear plug lamination. The observed pregnancy rate of adult females was 60 percent; the true rate is calculated at 43 percent. No cases of multiple pregnancies, or simultaneous pregnancy and lactation, were observed.

All humpbacks were infested with the sessile barnacles *Coronula diadema* and *C. reginae*. All but one had stalked barnacles *Conchoderma auritum* growing on the sessile barnacles. On the sessile barnacles, rock barnacles *Balanus* spp. were found twice, and hydroids *Obelia* sp. were found three times. Whale lice *Cyamis boopis* were also found on every whale; the legs of the lice harbored an undescribed genus of chonotrich ciliate. The scars of lampreys *Lampetra tridentata* were found on only 24 (16 %) of 147 whales examined. Diatoms *Licmophora* sp. commonly form a scum on the barnacle shells; up to 80 percent of the whales are so infested by August and September. The small nematode *Odontobius* was found in one sample of baleen film.

Endoparasites are not very frequent in humpback whales. Liver flukes *Lecithodesmus* sp. were found in one animal. Another was infested with the large tapeworm *Diplogonoporus balaenopterae*. Stomach worms *Anisakis* were found in 30 (19 %) of 151 stomachs examined. Kidney worms *Crassicauda* sp. were found in three (75 %) of four animals carefully examined. An acanthocephalan *Bolbosoma* sp. was found in the intestines of two animals.

GRAY WHALE *(Eschrichtius gibbosus)*.

Migrating gray whales pass southward along the coast of central California from December to February, and return northward from February to April. They are normally absent during the summer, but one remained near Pigeon Point in the summers of 1951 and 1952.

The stomachs of all six gray whales, taken during the northward migration, were empty.

The one female in her first pregnancy had about 11 ear plug laminations and was 12.7 m (42 ft) long. Males attain sexual maturity when they have accumulated 10 laminations, at a mean length of about 11.9 m (39 ft).

A female taken on 23 February contained a 40

is, indicating that conception had occurred anuary or early February.

gray whales were infested with the en- arnacle *Cryptolepas rachianecti*. All har- e cyamid *Cyamus scammoni*, and five (83 e six were infested with *Cyamus ceti*.

ne endoparasite was found, a small cestode ntly *Tetrabothrius)* in the intestines of two f the six animals.

RM WHALE *(Physeter macrocephalus)*.

sperm whales are found the year round in rs off central California, but females have nd only from April to May and from August er.

ief food of sperm whales in the waters off California are the large squid *Moroteuthis* and the longnose skate *Raja rhina*. The y of occurrence of these and other items nted in table 2.

ale sperm whale 9.3 m (30.3 ft) long was immature; all other females, 9.9 to 11.6 m 38.0 ft) long, were sexually mature; a 10.1) female in her first pregnancy had 9 den- inations. A 9.1 m (30 ft) male with 8 den- inations was sexually immature; all other 8 to 16.5 m (32 to 54 ft) long, were sexual- e. (These data on length at sexual maturi- oubtless biased towards the high side be- the 10.7 m (35 ft) legal length limit.)

eeding season, determined by extrapolating wth curves, is April through August; par- occurs from August to December. Of 26 nales, 10 (39 %) were pregnant, 7 (26 %) ating, and 9 (35 %) were neither pregnant ting.

rasites were rare on sperm whales. A few s *Coronula reginae* were present on 6 (6 %) ales. The scars of the lamprey *Lampetra a* were found on 36 (64 %) of 56 sperms l for this feature.

species of endoparasite were recorded. the tapeworm *Phyllobothrium delphini* sent in at least 26 (65 %) of 40 whales lubber was carefully inspected. Stomach *nisakis* sp. were found in 88 (88 %) of 99 examined. The giant nematode *Placento- antissima* was found in all four whales term fetuses whose placental membranes nined.

BOTTLENOSE WHALE *(Berardius bairdi)*

ose whales are frequently seen off the alifornia coast from at least June to October, but they are infrequently taken because of their relatively small size.

Food remains were present in the stomachs of six of the eight examined: Two contained mostly fish remains (not yet identified); two contained mostly squid (some identified as *Gonatus fabricii)*; one contained 60 percent fish and 40 percent squid *(Onychtoteuthis* sp.); and one contained squid *(Onychoteuthis* sp.), octopus (Octopoda; genus undetermined), and a rough-scaled rattail *(Coryphaenoides acrolepis)*. Trace items included an amphipod, a few crab legs, a large crustacean antenna (?), and egg capsules of skates *(Raja* sp.). Two stomachs were empty.

No female bottlenose whales were examined by biologists, but on 21 October 1957, the Del Monte Fishing Company took an 11.0 m (36 ft) female with a 2.1 m female fetus.

One male, 10.2 (33 ft) long, had testes weighing 2.3 kg and unfused vertebral epiphyses. The other seven males, 10.1 to 11.2 m (33 to 37 ft) long, had testes weighing 7.0 to 17.6 kg and fused vertebral epiphyses.

Ectoparasites on bottlenose whales included the barnacle *Conchoderma auritum* on the teeth of three (38 %) of the eight; cyamids *Cyamus* sp. (cf. *C. catodontis)* on four (50 %).

Cysts of the tapeworm *Phyllobothrium delphini* were found in one (25 %) of four whose blubber was carefully examined. Nematodes *Anisakis* sp. were found in the stomachs of seven (88 %).

Acknowledgments.

John Caito and Charles Caito of the Del Monte Fishing Company, and Robert Casebeer of the Golden Gate Fishing Company, generously placed the facilities of their stations at my disposal. Catcher boat captains Edward Holloway, Gilbert Hunter, Loyd Newton, Harold Ridle, and Grant Yost, and their crews, allowed me to make trips aboard their vessels and supplied much useful information. Biological aids Thomas J. McIntyre, John R. Stennick, and Richard Bonn, Fisheries Management Agent Lawrence Knapp, and Raymond M. Gilmore, assisted in much of the field work. Clifford H. Fiscus assisted in the identification of squids. Leo Margolis, John L. Mohr, Kenneth A. Neiland, and Robert L. Rausch identified, or are currently studying, the parasites.

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Table 1. The number of whales taken by the two California shore stations from 1956 through 1962, and, in parentheses, the number examined by biologists from 1959 through 1962.

Year	Blue	Fin	Sei	Humpback	Gray**	Sperm	Bottlenose	Killer	Total
1956		3		133		9			145
1957		22	1	199		14	1		237
1958	26	109	2	115		8	1		261
1959	5(5)	108*(69)	37* (19)	140(68)	2(2)	17(8)	2(2)		311(173)
1960	1(1)	138 (61)	47 (24)	67(27)		16(9)	2(2)		271(124)
1961	2(1)	118 (96)	51 (26)	62(50)		101(73)	4(4)		338(250)
1962	2(2)	124 (103)	22 (19)	39(23)	4(4)	60(38)		1(1)	252(190)
Total	36(9)	622 (329)	160 (88)	755(168)	6(6)	225(128)	10(8)	1(1)	1,815(737)

* These figures differ from those published in the International Whaling Statistics, because two fin whales were erroneously reported as sei whales.

** Collected under Special Scientific Permits.

Table 2. Frequency of occurrence of food items in the stomachs of 54 sperm whales.

Species		Frequency of occurrence
Squid		52(96%)
Moroteuthis robusta	22(41%)	
Gonatopsis borealis	10(19%)	
Onychoteuthis sp.	2(4%)	
Unidentified	22(41%)	
Octopus		
Octopus sp.		6(11%)
Longnose skate		
Raja rhina		13(24%)
Brown cat shark		
Apristurus brunneus		5(9%)
Pacific angel shark		
Squatina californica		1(2%)
Sablefish		
Anoplopoma fimbria		2(4%)
Lingcod		
Ophiodon elongatus		2(4%)
Unidentified teleost fishes		9(17%)
Miscellaneous*		
Lanternfish *(Tarletonbeania crenularis)*		1
Gorgonians *(Gorgonacea)*		1
Shoe		1

* Apparently inadvertently ingested items.

CUMULATION OF RADIONUCLIDES BY AQUATIC ORGANISMS

by

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Laws have been established to govern waste disposal actices and health regulations so as to protect man's environ- nt. These laws do not permit a deliberate contamination an estuary with radioactive materials. To implement these gulations the Radiobiological Program at Beaufort is en- avoring to collect sufficient data that can be used to predict dangers to aquatic organisms which could arise from an entional or accidental release of radioactive wastes into estuary or an ocean area. In order to obtain accurate presentative data it is necessary to compare the data obtained the laboratory with data obtained from a natural environment. r this reason the cooperative program on the Savannah Estuary onsored by the Public Health Service and the Bureau of Com- rcial Fisheries is a satisfactory arrangement, since this ogram allows for a comparison of laboratory data with field ta. In addition to data comparison, a transition from labora- y to field conditions will be obtained by studies on presently lluted estuaries and from controlled experiments in tanks d ponds. These controlled experiments can be referred to pilot-model experiments and serve as a testing area for rtain questionable findings arising from laboratory experi- nts. By using tanks and ponds, the desired isotope in the quired quantities can be followed after introduction into the ter; competition among organisms for this material can be served, and the pathways in the food web taken by a particular dioisotope can be identified.

When the Maximum Permissible Concentrations (MPC's) re calculated for the different radionuclides which occur in inking water, the assumption must have been made that such ncentration of radionuclides in the aquatic environment would sult in not only an insiginificant return of activity to man, t would also be of no harm to aquatic organisms. This as- mption has not been validated and will require the collection considerable data before any confidence can be attached to Radionuclides in these permissible concentrations may adversely affect aquatic organisms which are used as food by man, or reduce the population of other organisms in the food web, thereby reducing the availability of food to man. It is known from experimental evidence that certain organisms, in addition to those of commercial value, serve as a vital link in certain food webs and can concentrate some radioisotopes to levels much greater than those occurring in the ambient water. The damaging effect that these concentrated radiation levels might have on the organisms must be determined.

With the expanding nuclear energy industry which has developed in less than 15 years, man will probably find that keeping his environment free from radioactive pollution will be more and more difficult. Thus a responsibility rests upon those who pollute the environment with these materials and upon those who must protect human health and insure the safekeeping of the living resources. Since it is definitely impracticable, if not impossible, to insure that no radioactivity will get into the environment, levels that are safe and rates at which radionuclides can be added to the aquatic environment must be known.

Since the amounts of the different radionuclides that can occur in the human body without undue danger are known, calculations can be made of the permissible concentrations of radionuclides which can occur in food, air, and water. If radioactivity reaching man comes from only one of these three sources, the concentration of radionuclides in that source may be larger than if the radioactivity came simultaneously from all three. If the only source of radioactivity to man from a particular aquatic environment is drinking water, it becomes relatively easy to make measurements on the water and keep levels below the MPC. However, should plants and animals from this area be used as food, then the extent to which they concentrate the different radionuclides must be known.

The organisms which concentrate a radionuclide to the highest degree are not necessarily the controlling factors in the disposal of radioactive wastes. Rather, the organisms which concentrate the radionuclide to the highest degree in relation to the amount eaten by man will be more important. For example, at Windscale, England, an exhaustive program was undertaken to study the principal bottom fish, a plaice, *Pleuronectes platessa*, andto determine its role in the passage of radionuclides to man (3, 4, 5). Movements of this fish were determined by tagging, and laboratory investigations were performed in which fish were kept in water containing radio-ctive materials so that the concentration factor, the ratio of oncentration of radioactivity in the water to that of the radioctivity in the various parts of the fish, could be obtained. spite of these logical studies with the plaice, however, the dible seaweed, Porphyra, which is eaten by man to a greater xtent than the plaice, was found to concentrate radionuclides such high levels that it became the limiting factor in the scharge of wastes from the Windscale Plants. Near the eactor of Winfrith, on the Dorset Coast of England, the lobster as found to be the critical animal limiting the discharge of adioactive wastes (9).

A number of reports have appeared in the literature conerning the occurrence of radionuclides in aquatic organisms sed as food by man (10, 13, 18). For instance, the concenation of Zn^{65} in oysters grown in Willapa Bay, Washington, e closest commercial oyster-producing area north of the olumbia River, appears to be substantially higher than in ysters from other areas. However, this higher concentration Zn^{65} need not concern us greatly; the amount of oysters om Willapa Bay which one must eat in order to obtain the aximum permissible body burden is given in table 1. The lculations are based on 10^{-3} microcuries per milliliter c/ml) as the maximum permissible concentration of Zn^{65} drinking water for occupational exposure, which is equivalent a sustained intake of about 2.2 μc/day assuming that the verage person drinks 2200 ml of water per day (12). An verage concentration of Zn^{65} in oyster meat from Willapa Bay as taken as 5×10^{-5} μc/g. It should be stressed that these ta are for sustained consumption and that the maximum permisble body burden associated with these rates will be reached nly if intake is continuous for 3 years or more (6).

Table 1.–Amounts of Oysters from Willapa Bay, Washington, Which Must Be Eaten to Obtain the Maximum Permissible Body Burden of Zn^{65} (7)

Premise	Sustained consumption rate to give exposure of premise
cupational Exposure - Handbook 69	700 pounds/week
sons in the neighborhood of controlled areas[1]	70 pounds/week
ggested I.C.R.P. apportionment for genetic dose[2]	7 pounds/week
ubling of natural background[3]	14 pounds/week

aken as 0.1 of values recommended in Handbook 69.

aking 0.01 of the Handbook 69 values as equivalent to an exposure of 1.5 rem to the gonads in 30 ears. It should be noted that the International Commission on Radiological Protection for genetic easons assumes that the entire population is exposed at this level. The oysters in this case contribute only a very small fraction of the total population.

ssumes that a continuous intake rate of 2.2μc/day results in 5 rem/year to the body and that natural ackground contributes 100 millirem/year.

In evaluating the health hazard and determining which organism will be the source of the largest amounts of radioactivity, it is necessary to know what radionuclides are present. Also, since all radioactive elements are not equally harmful, it will be necessary to know the amount of radionuclides present in the water and the duration of their presence If their presence is for only a short period of time, organisms which have high metabolic rates, large surface areas, or mechanisms for rapidly removing the radioactive materials from the water may be the most radioactive after a few hours. Organisms which have slower rates of accumulation but which have higher concentrating capacities could be as radioactive if they were given sufficient time to achieve uptake.

For a few days to weeks following the detonation of an atomic bomb, large numbers of radioisotopes are found in plankton and other aquatic organisms in the vicinity of the explosion. It is not until several weeks later that the number of isotopes becomes limited and an association of specific isotopes with certain organisms and tissues can be established. The distribution of radioisotopes in the biota varies from organism to organism and is strikingly different for aquatic and terrestrial forms. Of the long-lived fission product isotopes (Sr^{90}, Cs^{137}, and Ce^{144}), only Ce^{144} enters significantly into the biological cycle in the marine environment. Of the induced radionuclides, Fe, Zn, Co, and Mn occur in largest concentrations in the biota. Some of the biologically more important radionuclides which either now or in the future may occur in the aquatic environment are listed in table 2.

Radioactive materials introduced into an aquatic environment such as an estuary can either (1) remain in solution, (2) precipitate and settle on the bottom, thereby exposing bottom organisms to more radiation, or (3) be taken up by plants and animals. Thus, three phases exist in such an environment: water, bottom or sediment, and biota. One mus understand that factors are in operation which tend to dilute and disperse radioactive materials while simultaneously other conditions are concentrating the radioactive substances (figure 1).

The amount of a nuclide in a unit weight of an organism in relation to the quantity of the same kind of nuclide in an equal unit weight of the organism's ambient water is referred to as the concentration factor. Concentration factors vary with season, concentration of the element in the water, concentration of other metabolically similar elements, age of the

Table 2.-Some of the Significant Radionuclides Which Have Occurred or May Occur as Pollutants in the Aquatic Environment

Eniwetok-Bikini Area (14)	Columbia River (3)	Waste from nuclear powered ships (2)
	Arsenic-76	
Cerium-144		Cerium-144
Cesium-137	Cesium-137	Cesium-137
Cobalt-57, -58, -60	Cobalt-60	Cobalt-60
	Copper-64	Copper-64
	Chromium-51	Chromium-51
		Iodine-131
Iron-55, -59	Iron-59	Iron-55, -59
Manganese-54	Manganese-54, -56	
	Neptunium-239	
Niobium-95		Niobium-95
	Phosphorus-32	
Rhodium-106		
Ruthenium-106		Ruthenium-106
	Scandium-46	
	Sodium-24	
Strontium-89, -90	Strontium-89, -90	Strontium-90
		Tantalum-182
Yttrium-91		
Zinc-65	Zinc-65	Zinc-65
Zirconium-95		Zirconium-95

organisms, sex, and a number of other conditions. Many oceanographers have maintained that all one has need for is the concentration factors for the particular radionuclides in as many organisms as possible. With this information, and a measurement of the radioactivity in the water, one can calculate the activity which will eventually occur in the organisms

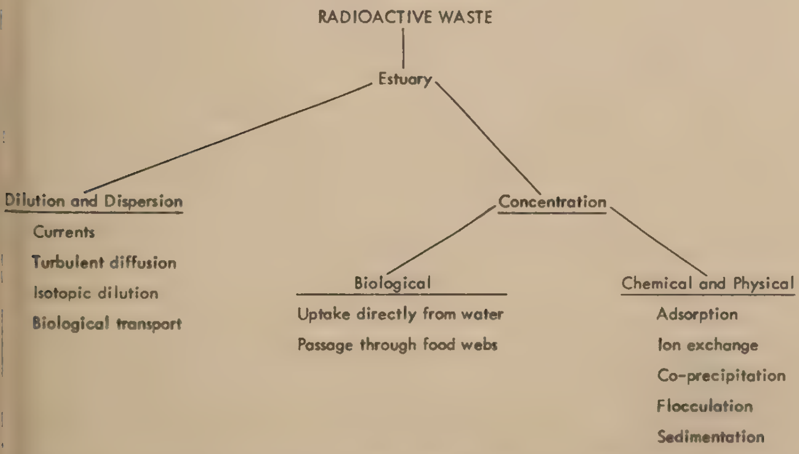

RADIOACTIVE WASTE
Estuary
Dilution and Dispersion
Currents
Turbulent diffusion
Isotopic dilution
Biological transport
Concentration
Biological
Uptake directly from water
Passage through food webs
Chemical and Physical
Adsorption
Ion exchange
Co-precipitation
Flocculation
Sedimentation

Figure 1.-A Schematic Diagram Showing the Processes Tending to Dilute or Concentrate Radioactive Materials Added to an Estuary

if the level of radioactivity is maintained in the water; one can also calculate the worst conditions that could occur but cannot develop data on concentration rates.

The uptake of a radioisotope depends both upon the metabolic need of the particular organism for the element and upon the amount of radioisotope in the water in relation to the total concentration of the element. Some investigators are of the opinion that the concentration reached by a radionuclide at equilibrium in an organism will be the same whethe or not the radionuclide was obtained from water or from food. In our opinion this may not hold true in all instances for all radioisotopes. An experiment with *Artemia* will demonstrate our point. This organism can live for about 4 to 6 months under the conditions in our laboratory. The experiment was followed for 22 days, or about one-fourth to one-sixth of the organism's lifetime, and there was no indication that the *Artemia* obtaining Zn^{65} from water would ever contain as much as those obtaining Zn^{65} from food. Another point shown by this experiment is that some small organisms, which may be important accumulators, might not live long enough to reac equilibrium. The rate of uptake, therefore, as well as the source of the isotope, will have a bearing on the eventual concentration reached in the organism.

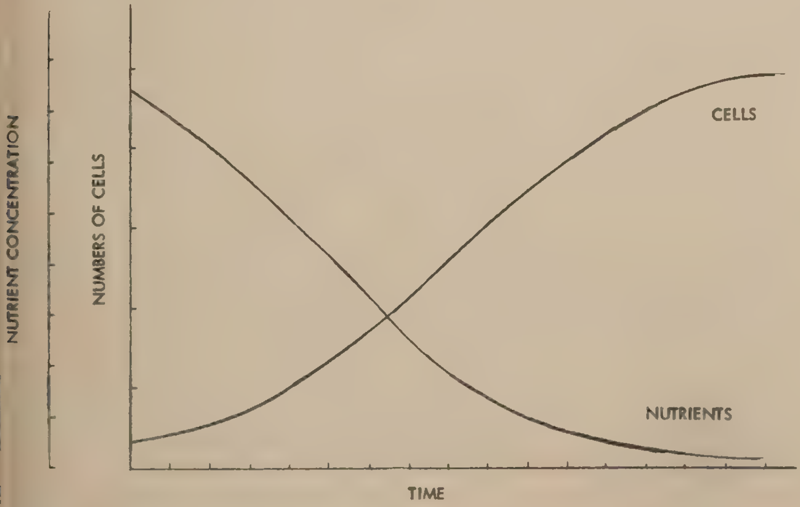
In our laboratory we found that phytoplankton accumulated every radioisotope present in a mixed fission product mixture when it was added to their culture medium. Also, experiments were run with natural populations of phytoplankton collected from the ocean near the laboratory dock and also 10 miles offshore. These populations when added to the culture medium rapidly removed radionuclides such as Ce^{144}.

Whether a radionuclide occurs in an ionic or a particulate state makes little difference in its uptake by plankton. If the nuclide cannot be metabolized by the cells, it may be adsorbe to the surface of the cells. However, such is not the case for the larger organisms which have a disproportionate ratio of surface area to body size. Also, particles usually cannot pass through the living membranes of the larger organisms and cannot, therefore, enter into their metabolism.

Many animals consume phytoplankton which serve not only as their food but also as a potential source of radioactivit to them. Davis et al. (2) state that all aquatic organisms whi inhabit the Columbia River downstream from the Hanford reactors contain concentrations of radioisotopes, but algae contain the most kinds and the largest amounts of isotopes.

Seymour (14) has found that plankton organisms in general will concentrate radioisotopes from sea water by a factor of one to many thousands and appear to be the best biological indicators of the presence of radioisotopes in the sea. In fact, if one wishes to know if an aquatic environment has received fallout, a radiological analysis of a plankton sample taken from that environment will provide this information.

In the aquatic environment many factors operate to replenish nutrients utilized for phytoplankton growth. Simultaneously, other factors tend to reduce the standing crop of phytoplankton cells. This combination of conditions may result in a rapid division of cells without any large variation in the number composing the standing crop. Similar conditions have not held for investigations in the laboratory on the uptake and concentration of nutrients and radioactive isotopes. Here the classical technique of growing cultures in confined volumes of medium subjects cells to more drastic conditions. Generally, a culture medium initially contains high concentrations of nutrients (see figure 2). As the cells increase in number, the nutrient concentrations are reduced until some factor becomes limiting and cell division is stopped. It may be that the concentration of a nutrient is initially present in such high quantities that a reduced rate of division results. With this slower division rate, the nutrient eventually is reduced to a level at which cell division may become optimum under



igure 2.-Theoretical Curve Showing Growth of Population of Algal Cells and Their Removal of Nutrients from a Confined Volume of Medium

the conditions and continue at this rate until the nutrient is further reduced to a concentration at which it becomes limiting, reducing the rate of division or stopping it altogether.

It is now questionable whether data obtained by the classical culture technique are representative of the processes occurring in the aquatic environment. Culture experiments in a confined volume of medium are short term and during the course of the experiment the population will go through all phases of the growth curve. Since the cells change physiologically as the population passes through these phases, it follows that the biochemical mechanisms controlling the uptake of radioisotopes may also change during the experiment. As nutrients are consumed and excreted products accumulate, the environment obviously changes with an increase in numbers of cells. As an example of complications that can result, an increase in pH during photosynthesis may alter the solubility characteristics of the radioisotope being studied.

Williams and Swanson (17) and investigators at our laboratory have used the classical culture technique in following the accumulation of Cs^{137} by phytoplankton. Williams and Swanson found that fresh water species concentrated Cs^{137} from 52 to 1, 530 times over its concentration in the medium. Our investigators (1) found that marine species concentrated Cs^{137} not more than 3. 1 times over levels in the medium. This difference in levels of concentration is due, no doubt, to the high concentration of potassium in sea water. Since the concentration factor represents the ratio of activity in a gram of organism in relation to that in a gram of water, a drastic reduction in the amount of activity in the water will obviously increase the concentration factor. In table 3 Williams gives the percentage of Cs^{137} removed from the medium during certain periods of time. These tabulated data show that on the fourteenth day Euglena cells had concentrated Cs^{137} about 706 times over amounts remaining in the medium. On that day, less than 18 percent of the original Cs^{137} was still in the medium. Using similar conditions, we found that Nannochloris cells removed only 0. 1 percent of the

Table 3.-Removal of Cesium-137 from Culture Medium by Euglena Cells (17)

Days	Percentage Cs^{137} removed
6	69
11	82
14	706 (concentration factor)
18	86
34	96

Cs^{137}. As is shown in figure 3, the uptake of Cs^{137} closely followed the growth curve of the cells. Since there is such a small reduction in the availability of Cs^{137} to Nannochloris, the concentration factor for Nannochloris cells should be representative of what occurs in the oceans.

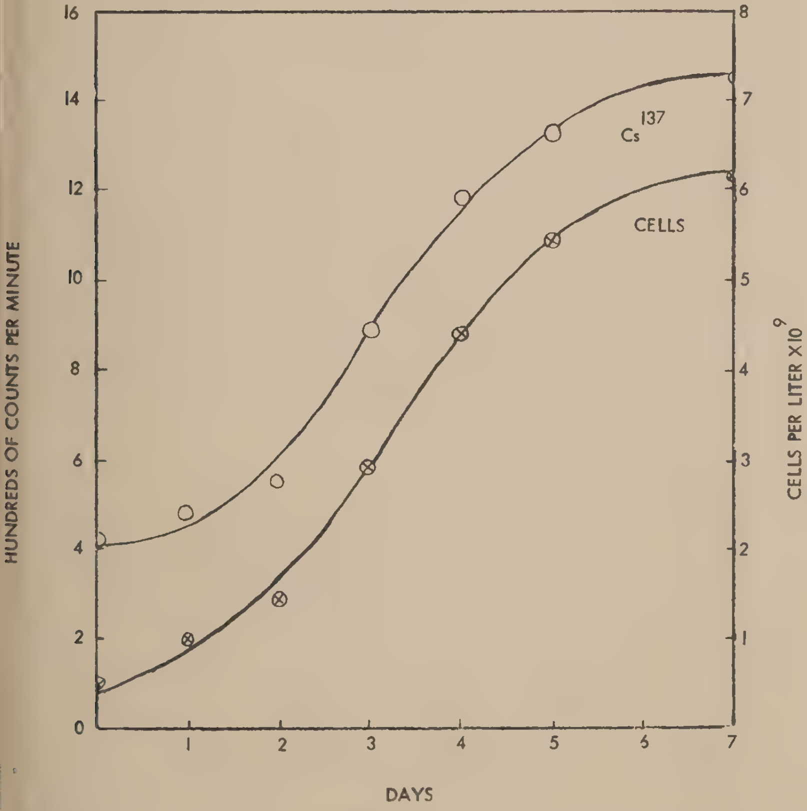


Figure 3.-Accumulation of Cs^{137} by a Population of Nannochloris Cells

To grow algae in the laboratory under conditions that more nearly simulate growth in a natural environment, a continuous culture system has been devised. Bacteriologists have used a similar culture apparatus called a chemostat. Both Dr. Taylor (15) of the Chesapeake Bay Institute and the author with the assistance of Marianne B. Murdoch, are using such a system for growing algae. With this culture method it is possible to maintain a constant population of cells in the culture container and a desired level of nutrients in the water. This insures that cells will grow under more nearly constant conditions similar to those occurring in nature.

The main components of the continuous flow system (figure 4) are a reservoir of culture medium, a continuous infusion pump, a pyrex resin kettle or growth chamber, and a discharge system to remove medium and cells at the same rate that new medium is pumped into the growth chamber. Cells are grown in the resin kettle which will hold 2,650 ml of medium and are kept uniformly dispersed by means of a Teflon magnetic stirrer. Inflowing medium is pumped from the reservoir to the growth chamber by the infusion pump. Flow rates can be controlled by selecting one of the 12 mechanical speed controls on the pump or by selecting any one of 5 different size syringes which can be adapted to the pump. The combinations give a choice of 60 flow rates ranging from 0.00 to 38 ml per minute. The population of cells can be stabilized at a given level by maintaining the flow of medium at a rate which will remove cells as rapidly as they are formed or by varying a limiting factor in proportion to flow rate so that an excess of cells will not accumulate. The flow system is kept in a constant temperature room with a temperature of 20° ± 2° C. Cells are grown in constant illumination provided by daylight fluorescent lamps.

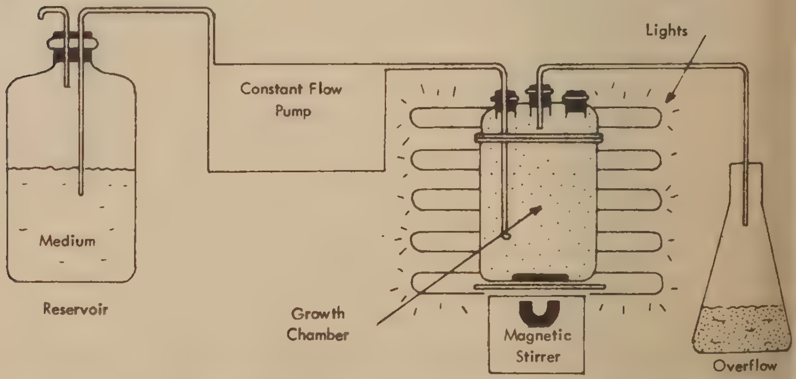


Figure 4.–A Continuous Flow System for Culturing Algae in a Controlle Concentration of Nutrients

The concentration of P^{32} from the medium by *Dunaliella* cells was followed at three different rates of flow. The medium contained 18 microgram atoms phosphorus per liter (μgAP/l) and all other conditions except flow rate were similar for the three experiments. After 3 days in the growth chamber, cells were filtered from the medium and a concenration factor was determined for the cells (table 4). As the low rate was increased, the concentration factor increased.

Table 4.-Effect of Flow Rate on the Concentration of Phosphorus-32 by Dunaliella Cells

Flow rate ml/day	Concentration factor
300	554
700	677
1400	934

The influence of the amount of phosphorus in sea water n the level to which it is concentrated by *Dunaliella* was ollowed since phosphorus is frequently the limiting nutrient n the oceans. Phosphorus was used in concentrations of 1, , and 60 µgAP/1.

Dunaliella cells were grown in medium containing no dded phosphorus until cell division ceased. Any further ivision by these cells would require additional phosphorus rom the medium. Sufficient cells to give a population size of 6 x 10^7 cells per liter were added to the growth chamber. nmediately before starting the inflow of new medium containng 1 µgAP/1, 5 microcuries of radioactive phosphorus were dded to the growth chamber and to the inflowing medium. A umping rate of 1,200 ml per day was maintained for the 4 ays during which time numbers of cells and concentrations of oth P^{32} and nonactive inorganic phosphorus in the medium ere followed. At the end of this time cells were filtered out f the medium, weighed, and their contained P^{32} measured. y comparing the P^{32} in a unit-weight of algae with that in the edium, a concentration factor was calculated. This proedure was repeated, using 6 µgAP/1 and again with 60 µgAP/1. n table 5 it can be seen that the higher the level of phosphorus n the medium, the lower the concentration factor.

Table 5.-Concentration of Phosphorus-32 by Dunaliella Cells when Grown in Medium Containing Different Levels of Stable Phosphorus

Phosphorus (µgAP/l)	Concentration factor
1	3,900
6	1,943
60	74

The concentration of Zn^{65} by Dunaliella cells was also etermined with all other conditions in the flow system similar xcept for the level of zinc in the culture medium (table 6). he cells grew in the growth chamber for 6 days before they were filtered from the medium and their concentration factors determined. As the zinc concentration in the medium was increased the concentration factor decreased.

Table 6.--Concentration of Zinc-65 by Dunaliella Cells when Grown in Medium with Different Levels of Stable Zinc

Zinc (μg)	Concentration factor
15	16,900
1500	11,500
3000	3,800

Dunaliella cells were also grown for 3 days in the flow system containing medium flowing at the rate of 700 ml per day and dosed with Cs^{137}. The cells were found to have concentrated radioactive cesium 12.6 times over the level in the medium.

Carteria cells were grown in the flow system which was set for a flow rate of 1,000 ml per day. After growing for 6 days in medium containing Sr^{85}, the cells were filtered from the medium and a concentration factor was determined. It was found the *Carteria* cells concentrated radioactive strontium 16.4 times over the level in the medium.

Mollusks are filter feeding animals and will concentrate in their digestive tracts or bodies any radionuclide occurring in or on phytoplankton. Thus, phytoplankton are an important step in the transmission of radioactive elements through certain food webs. The rate of accumulation, level of concentration, mode of entry, and assimilation of specific radionuclides by mollusks will depend largely on the physical state of the nuclides in the water and on the physiological demand of the mollusks for the element. Elements and their radioisotopes are present in sea water as particles and ions. A particulate radionuclide will become associated with molluskan shellfish by adsorption to the shellfish's body surfaces; if ingested, the radionuclide will pass through the digestive tract with only a small amount being assimilated. Ionic radionuclide readily pass through tissue membranes and are, therefore, assimilated to higher levels.

The giant "killer" clam of the tropic Pacific, *Tridacina*, concentrates Co^{57}, ^{58}, ^{60} and Mn^{54} in its kidney, or hepatopancreas (8, 16). Radioactive cobalt, manganese, and zinc are concentrated by the tropical horse clam, *Hippopus*. Stable zinc is present in the Hippopus kidney at a level 17 times as high as that in the *Tridacina* kidney. Also Ru^{106}-Rh^{106} and r^{95}-Nb^{95} are concentrated in the visceral mass of these lams.

Experiments conducted by Thomas J. Price of our labora- ry have shown that Sr^{89} is not concentrated in the soft tissues oysters and clams over the Sr^{89} levels found in the ambient ater; however, the shells do concentrate Sr^{89} about 10 times er amounts in the water. Oysters, clams, and scallops ere found to take up Cs^{137} over its concentrations present the sea water. In a comparative experiment lasting for days, oysters accumulated Cs^{137} 5 times over this nuclide's ncentration in the sea water, while clams had an accumula- on factor of 6. By the tenth day, the adductor muscles of allops concentrated Cs^{137} 10 times more than the level in e water and continued thereafter to take up more Cs^{137}. ne visceral mass of the scallop had accumulated the radio- clide only 8 times.

The blue crab is an omnivorous predator and scavenger d during its planktonic larval stages feeds on the zooplankton d possibly phytoplankton. Thus, it is involved in many of e trophic levels. Pollutant radionuclides which are accumu- ted by virtually any of the estuarial plants and animals will obably find their way into the tissues of the crab because of e great variety of plant and animal material, both living d dead, which the crab consumes. Moreover, since it ems to be beyond the powers of invertebrates to develop npermeable membranes, radionuclides present in the water e expected to accumulate in the tissues of crabs. There is constant movement of water and ions between the crab and s ambient water, and it has been shown that even the crab's avy carapace is permeable to water and salts (8), although, is the case with virtually all living membranes, it is more rmeable to water than to salts.

In experiments carried out by George H. Rees of our boratory, it was found that Sr^{85}is concentrated in the exo- eletons of crabs 25 to 50 times over its concentration in e water. This radioactivity is lost, together with the old oskeleton, when molting occurs. Strontium-85 is not con- ntrated in the soft tissues over its concentration in the water.

Zinc-65 is taken up rapidly from the water and accumu- tes in all the tissues of blue crabs. The largest concentra- on of this isotope is reached in the hepatopancreas followed gonad and muscle. After 29 days in sea water containing n^{65}, blue crabs had reached a whole body concentration of times the concentration of this nuclide in the water.

Cerium-144 administered orally to blue crabs is excreted rapidly with very little being assimilated from the digestive tract. Twenty-four hours after administration, less than 4 percent of the original dose remained in the animals, most of this in structures associated with the alimentary canal. Radiocerium present in the water is accumulated in all the tissues of the crabs, apparently as the result of passage through the gill membranes into the blood. The gills themselves, by adsorption to their surfaces, take up Ce^{144} and concentrate this isotope several hundred times greater than its concentration in the water.

Radioisotopic concentrations of different tissues have been determined for adult fish from the Columbia River. Radioactive phosphorus was the dominant radioisotope, but significant concentrations of Zn^{65} were found to occur in all tissues (2). Zinc-65 in the retina and iris of the eye was 3 or more times greater than in any other tissue. Other radioisotopes occurring in fish tissues were Na^{24}, Sc^{46}, Cr^{51}, Mn^{54}, Fe^{59}, Co^{60}, Cu^{64}, Zn^{65}, Cs^{137}, Sr^{89}, and Sr^{90}.

Donald E. Hoss of our laboratory has found that fish may accumulate more radioactivity from food than from water. During an experiment followed for 92 days, more Zn^{65} was accumulated by postlarval flounder from food than from Zn^{65}-dosed water, even though the fish in the dosed water had 10 times as much of the isotope available to them. At the end of the 92-day period, the flounder continued to accumulate Zn^{65} at a faster rate from food than they did from water. Growth data indicated that for the two different experiments fish were growing at the same rate. The accumulation of Zn^{65} was found to be rapid in the digestive tract, liver, kidneys, and gill filaments, while in bone and muscle it was slower.

Fish accumulate radioactive materials by adsorption to their surface areas, absorption from the surrounding medium or by ingestion. In nature these three modes of uptake can occur simultaneously, singly, or in various combinations depending on the water, the food habits of the fish, the length of time an area has been radioactively polluted, or the length of time the fish remain in the polluted area.

Only a few fission products were found in the reef and lagoon fishes of the Pacific test area, but induced radioisotopes were present. Ranked in order of abundance, these were: $Fe^{55, 59}$, Zn^{65}, $Co^{57, 58, 60}$, and Mn^{54} (14). Oceanic fishes differed from reef and lagoon fishes in that Zn^{65} ranke rst in oceanic fishes. Tuna collected in the open sea near e test site contained Zn^{65} and Fe^{55}. The greatest concenration of radioisotopes in the tuna was found in the alimentary ract. For the different tissues, the descending order of upke was liver, skin, bone, and muscle. Strontium was taken p from the water by fishes and concentrated to the highest vels in bone and scales. It has been reported that a disrimination of from 3 to 10 against strontium in favor of calium occurred in most fishes. Rare earth radionuclides ere concentrated chiefly in the internal organs, while Cs^{137} as concentrated to the greatest extent in the muscle tissue.

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THE ROLE OF PHYTOPLANKTON IN THE CYCLING OF RADIONUCLIDES IN THE MARINE ENVIRONMENT

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Reprinted from PROCEEDINGS OF THE FIRST NATIONAL
SYMPOSIUM ON RADIOECOLOGY. 1961
Edited by Vincent Schultz and Alfred W. Klement, Jr.

THE ROLE OF PHYTOPLANKTON IN THE CYCLING OF RADIONUCLIDES IN THE MARINE ENVIRONMENT

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INTRODUCTION

Animal life in the oceans is dependent either rectly or indirectly upon the photosynthetic tivity of unicellular algae. Phytoplankton roughout the great expanse of the oceans grow the upper few hundred feet. Their small size sists them in remaining suspended, while their st numbers and large surface to weight ratio ovide a tremendous area for direct adsorption elements. Phytoplankton affect their envi- nment by removing nutrient elements and their dionuclides, by changing the pH, and by ex- eting biologically active substances. Not only they serve as food for filter-feeding animals ile alive and in suspension, but after death ey settle to the bottom where they either be- me food for detritus-feeders or decompose and turn to the environment nutrient elements used the synthesis of organic substances. The se- ence of "eat and be eaten" is very complex in e oceans with phytoplankton at the bottom of st food webs.

Since phytoplankton have a large surface ea per unit weight upon which adsorption occurs d since they absorb from the water a large num- r of elements essential for life, it can be as- med that they will be very instrumental in the moval of radionuclides from both fresh water and a water. That this is a correct assumption is nfirmed by several investigators. Davis et al. 958) have observed in the Columbia River down- ream from the Hanford reactors that algae con- ined the most kinds and largest amounts of most dionuclides. Similarly, marine plankton are ported to concentrate radionuclides to high vels. Seymour (1959) stated that plankton in neral will concentrate radioactivity from sea ter by a factor of one to many thousands and pear to be the best biological indicators of e presence of radionuclides in the oceans. In r laboratory we have observed that in a very ort time nearly all the radioactivity of a xed-fission-product solution added to cultures marine phytoplankton becomes associated with e cells.

The importance of phytoplankton in cycling dionuclides varies with space and time. Some eas of the oceans are poor in nutrients and erefore support only a limited population of ytoplankton. Other areas, where upwelling oc- rs and nutrients are replenished to the surface ters, support larger populations. Populations estuaries or over the continental shelf, par- cularly in those areas influenced by nutrients pplied by river flow, will probably be larger an those in the open ocean. Those occurring at y one location fluctuate seasonally. In the rth Temperate Zone a rapid increase in the anding crop of phytoplankton generally occurs the spring, usually terminating in May or June, llowed by a second smaller increase in numbers late August, September, or October. This fall oom terminates in late October, November, or rly December, and the standing crop during the nter months is much reduced.

Contamination of the marine environment can occur from fission products and induced radionuclides. Fission products are formed by the splitting of the nucleus of a uranium or plutonium atom, while induced radionuclides result from the capture of a neutron by a stable nuclide. The radionuclides that will occur from fission are known, but the induced radionuclides can vary since they are isotopes of elements that are present in the area of a neutron flux. Many radionuclides can be formed by the above phenomena during a nuclear detonation or otherwise can find their way into the marine environment. Some have half-lives in terms of seconds and minutes which is too short a half-life to be of biological significance.

Some of the factors determining the importance of phytoplankton in the cycling of radionuclides which are discussed in this paper are as follows: (1) the capacity of the phytoplankton to take up radionuclides from sea water, (2) the length of time these radionuclides are retained in the protoplasm or on the surface of the cell, (3) the rate of filtering of cells from sea water by animals as influenced by size of cells and total number of cells in the water, and (4) the digestability of different species of phytoplankton by filter-feeding animals. Also, a comparison is made of phytoplankton and water as sources of radionuclides to animals.

ACCUMULATION OF ELEMENTS AND THEIR RADIONUCLIDES

Metabolic requirements of phytoplankton populations for nutrient elements have been determined by changes in the nutrient salts in the water, chemical analysis of natural populations, and refined experiments in the laboratory with unialgal and pure cultures. The complete removal of both nitrate nitrogen and phosphate phosphorus from the surface water of the sea at about the same time by the rapid growth of phytoplankton has been observed many times (Harvey, 1926; Redfield, 1934). From these observations one can assume that other essential elements and their radionuclides occurring in the oceans in small concentrations will be significantly reduced by phytoplankton. The chemical composition of natural populations is indicative of the relative proportions in which nutrients were assimilated under specific conditions of growth.

Considerable knowledge pertaining to mineral metabolism has been accumulated since the suggestion was first made that plants may require a number of inorganic elements for growth. It was ten years after Sachs (1860) presented his nutrient formula for higher plants that similar solutions were employed for algae, and another 20 years before Beijerinck (1890) used bacteriological techniques to isolate individual species of algae for study. As early as 1896 Molisch stated that the mineral nutrition of algae was similar to that of higher plants. This general conclusion has been reaffirmed many times. By 1920 many species of algae had been isolated in a bacteria-free state, and investigations were conducted under controlled conditions. At first, qualitative studies of nutritional requirements predominated. However, during the last 20 to 30 years many quantitative investigations have been undertaken. Most investigations of nutrition to date have been made on species of algae which are relatively easy to culture (Ketchum, 1954). It is possible that these algae may differ in nutrition and physiology from those which are difficult to culture. Thus the interpretation of observations on populations in natural environments, based on laboratory findings, must be made with caution.

Phytoplankton may be of little importance in passing certain radionuclides to animals. Included among these are radioisotopes of strontium and cesium. The diatom *Nitzschia closterium* was found to concentrate strontium only 17 times over levels occurring in sea water (Rice, 1956). Experiments in which cesium-137 was used revealed that, while different species concentrated cesium to different levels (Table 1), none of the nine species tested showed any large concentration of this element from sea water (Boroughs et al., 1957).

Table 1. Concentration of cesium by marine algae (Boroughs et al., 1957).

Algae	Concentration factor[1]
Bacillariaceae	
Nitzschia closterium	1.2
Amphora sp.	1.5
Nitzschia sp.	1.7
Chlorophyceae	
Chlamydomonas sp.	1.3
Carteria sp.	1.3
Chlorella sp.	2.4
Pyraminonas sp.	2.6
Nannochloris atomus	3.1
Rhodophyceae	
Porphyridium cruentum	1.3

[1] The concentration factor is reported as the ratio of cesium-137 in the algae (wet weight) to that in an equivalent weight of sea water at an apparent steady-state condition.

The availability of a radionuclide to phytoplankton is dependent to a large extent upon its physical state in sea water. It is known that a large number of many elements in sea water occur in the colloidal and particulate states. That this holds for fission product elements in laboratory experiments designed to simulate an underwater nuclear explosion has been shown by Greendale and Ballou (1954). They predicted the physical states of the fission product elements and had their predictions partially confirmed by field observations. The physical states of fission product elements following their vaporization in sea water are given in Table 2. Most of the elements listed below tellurium occur in sea water in the colloidal or particulate states.

Table 2. Physical states of elements in sea water (Greendale and Ballou, 1954).

Element	Percentage in given physical state		
	ionic	colloidal	particulate
Cs, cesium	70	7	23
I, iodine	90	8	2
Sr, strontium	87	3	10
Sb, antimony	73	15	12
Te, tellurium	45	43	12
Mo, molybdenum	30	10	60
Ru, ruthenium	0	5	95
Ce, cerium	2	4	94
Zr, zirconium	1	3	96
Y, yttrium	0	4	96
Nb, niobium	0	0	100

If adsorption by phytoplankton of colloids and particles of elements listed in Table 2 is similar to that discussed below, then phytoplankton will be very instrumental in cycling radionuclides occurring in the oceans in the particulate state. That an element in the particulate state can be assimilated by phytoplankton has been demonstrated many times. Harvey (1937) showed that diatoms are able to take up ferric hydroxide or ferric phosphate in colloidal or par-

Goldberg (1952) using radioactive iron found that the marine diatom *Asterionella japonica* utilized only particulate and/or colloidal iron as a growth nutrient, whereas ionically complexed ferric ion as the citrate, ascorbate, or artificia humate was not available for uptake. The removal of yttrium-90 from culture medium by *Carteria* was shown by Rice (1956) to be due to adsorption on the surface of the cells (Table 3). The uptake of yttrium-90 was quite different from the uptake of radioactive strontium, which was related to metabolic processes. More than half of the yttrium-90 in the cells after 72 hours was present after 15 minutes.

Table 3. Uptake of radioactive strontium and yttrium by *Carteria* cells (Rice, 1956).

Hours exposed	Strontium activity (counts per minute)	Yttrium activity (counts per minute)	Percentage activity from yttriu
1/4	69	592	89.56
6	527	735	58.24
24	4,800	848	15.01
48	23,619	898	2.47
72	34,769	948	2.65

The continued uptake of small amounts of yttrium-90 occurred since it was being formed with time by the decay of strontium-90. Also Rice (1959) founc that cerium-144 occurring in medium in the particu late state was taken up at a faster rate by *Nitzsc ia* cells than cerium-144 occurring in the ionic state (Table 4). The concentration of cerium-144 by several species of algae is shown in Table 5. The accumulation of ruthenium-106 by phytoplankto was followed in our laboratory and was found to be similar to that of cerium-144 (Figure 1).

Table 4. Percentage uptake of ionic and particulate cerium-144 by *Nitzschia* cells with time (Rice and Willis, 1959).

Hours exposed	Ionic	Particulate
0.5		52.4
9.0	36.3	83.0
24.0	56.9	84.6

Table 5. Number of times cerium is concentrated over the amount in sea water by planktonic algae (Rice and Willis, 1959).

Algae	Concentration of cerium-14	
Exposed:	0.5 hours	24 hours
Carteria sp.	314	2,422
Platymonas sp.	1,843	2,127
Nitzschia closterium	518	1,970
Thalassiosira sp.	2,610	3,346
Amphidinium klebsi	3,001	4,498
Porphyridium cruentum	802	3,344

The accumulation of a radionuclide by phytoplankton depends upon both the total amount of the element present in sea water and the quantities of other metabolically similar elements. Ketchum (1939) and Goldberg et al. (1951), workin with marine diatoms, have shown that phosphate uptake is proportional to the concentration in the medium over a wide range. Similar findings have been reported for strontium (Rice, 1956) and for zinc and cesium (Rice, unpublished). Related elements with similar chemical properties tend to be taken up approximately in the same proportions as they exist in the environment. This is true, for example, of calcium and strontium, and of potassiu and cesium. There are approximately 13 milligrams of strontium per liter of sea water and 400 milligrams of calcium. Thus, phytoplankton would need a tremendous metabolic demand for strontium and clides of these elements could be accumulated. milarly, even though cesium is found in sea water a concentration of only 0.002 milligrams per ter it is not concentrated to very high levels ince it is chemically similar to potassium which curs in a concentration of 380 milligrams per iter. Another reason for a reduced uptake of sium is that it has not been shown to be essential for plant growth.

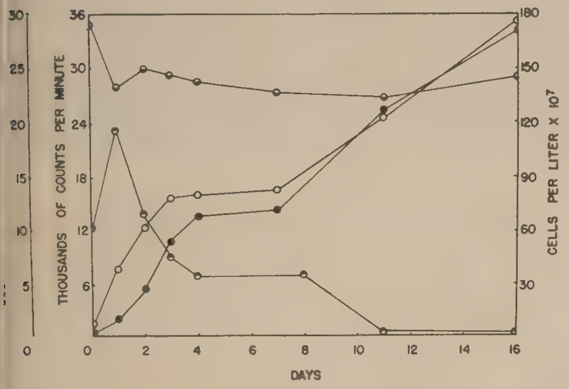

Figure 1. Uptake of cerium-144 by dividing *Nitzschia* cells and loss of cerium-144 from control medium (Rice and Willis, 1959). ◒ = counts per minute contained in 40 cubic centimeters of medium from control culture; 0 = counts per minute in cells from 40 cubic centimeters of medium; ● = population growth curve of *Nitzschia* cells; ◓ = counts per minute per cell.

That the concentration of calcium in the edium does influence the uptake of strontium can e seen in Table 6. Approximately the same perentage of radioactive strontium was accumulated y *Carteria* cells when grown in artificial sea ater medium with the three highest concentrations f calcium (Rice, 1956). Cells in medium with nly 0.075 grams of calcium per liter removed omewhat more strontium, while cells in medium ith no added calcium took up the most strontium. *annochloris* cells grown in artificial sea water edium containing no added potassium took up 5.7 imes as much cesium-137 as other cells grown in edium containing sea water concentrations of otassium (Rice, unpublished).

All species of phytoplankton will not be qually important in the cycling of all radiouclides in the oceans, based on their capacity o concentrate the radionuclide. This has been hown in a comparison of the simultaneous accuulation of radioactive strontium and yttrium by 2 species of phytoplankton (Rice, 1956). In able 7 it can be seen that with the exception of *arteria* and *Thoracomonas*, the species of algae ested concentrated radioactive yttrium to a much reater extent than radioactive strontium.

Table 6. Effect of calcium concentration on uptake of strontium (Rice, 1956).

Calcium added grams per liter)	Percentage radioactive strontium in cells
0.300	40.0
0.275	38.6
0.150	38.9
0.075	45.6
0.000	54.1

LOSS OF RADIONUCLIDES BY BIOLOGICAL DILUTION AND EXCHANGE

For phytoplankton to be of importance in the passage of radionuclides up the food web it is not only necessary that the cells accumulate the radioactivity, but also that it be retained for considerable periods of time. This is of particular importance when there is only a single addition of radioactivity to sea water or in instances of acute pollution. With the passage of time phytoplankton continue to divide but the availability of the radioactivity to the cells continues to decrease. Each phytoplankton cell becomes less and less radioactive by continued division without further uptake of radioactivity. This is due to "biological dilution" or the reduction by cell division of radioactivity per unit weight of protoplasm. If conditions are suitable for rapid cell division, the radioactivity within the cell can be drastically diluted in a relatively short time, a 50 per cent reduction of activity per cell occurs with each division.

The amount of phosphorus-32 exchanged by *Nitzschia* cells varied with the concentration of phosphorus in the medium in which the cells were grown, the physiological condition of the cells, that is, whether they were phosphate-deficient or nondeficient, and the length of time the cells were grown in medium containing phosphorus-32 (Rice, 1953). Cells grown in the higher phosphorus concentration lost a larger percentage of phosphorus than cells grown in a lower concentration regardless of time in the medium or the physiological condition of the cells (Table 8). Phosphate-deficient cells kept for 20 hours in medium containing phosphorus-32 lost less phosphorus than nondeficient cells kept for 20 hours in a similar medium. Nondeficient cells kept for seven days in medium containing phosphorus-32 lost a smaller percentage to the medium than nondeficient cells kept for 20 hours in the same type of medium.

Table 7. Differential uptake of radioactive strontium and yttrium by algae (Rice, 1956).

Species	Percentage activity from strontium	Percentage activity from yttrium
Carteria sp.	100.0	
Thoracomonas sp.	50.4	49.6
Amphora sp.	10.0	90.0
Navicula sp.	8.5	91.5
Chromulina sp.	8.2	91.8
Chlamydomonas sp.	6.5	93.5
Nitzschia closterium	6.0	94.0
Nannochloris atomus	5.7	94.3
Chlorella sp.	5.3	94.7
Porphyridium cruentum	4.4	95.6
Gymnodinium splendens	4.1	95.9
Gyrodinium sp.	2.3	97.7

Table 8. Exchange of phosphorus by *Nitzschia closterium* cells (Rice, 1953).

Phosphorus in medium[1]	Length time cells in phosphorus-32 medium	Physiological condition of cells	Percentage of phosphorus exchanged
45.5	20 hours	Nondeficient	30.6
	20 hours	Phosphate deficient	5.1
	7 days	Nondeficient	2.2
1,137.5	20 hours	Nondeficient	92.7
	20 hours	Phosphate deficient	25.4
	7 days	Nondeficient	17.3

[1] Microgram atoms of phosphorus per liter.

FILTERING RATES OF ANIMALS

Even though phytoplankton remove large amounts of radionuclides from sea water, the amount that can be passed up the food web will vary with cell size and total numbers of cells in the water. The size and number of particles present in the water are among the more important factors affecting the efficiency of the filtering mechanism of filter-feeding animals. Since both species (size) and numbers of cells fluctuate with space and time, the importance of phytoplankton in passing radioactivity up the food chain will vary in a similar manner. The effects of both cell size and numbers of phytoplankton cells in the water upon the filtering rate of the hard clam, Mercenaria mercenaria, have been determined by Rice and Smith (1958) with cells labeled with radioactivity.

Size of cells affects their rate of removal from water by the filtering activity of the hard clam (Figure 2). The slopes of the curves showing the removal of the two small green forms, Nannochloris and Chlorella, were similar. Also, the rates of removal of the two diatoms, Nitzschia sp. and Nitzschia closterium, were in close agreement. Even though the number of cells present in suspension was the same for the green algae and the diatoms, the diatoms represented a larger amount of protoplasm and would contain more radionuclide of those accumulated equally per unit weight of protoplasm by the different species.

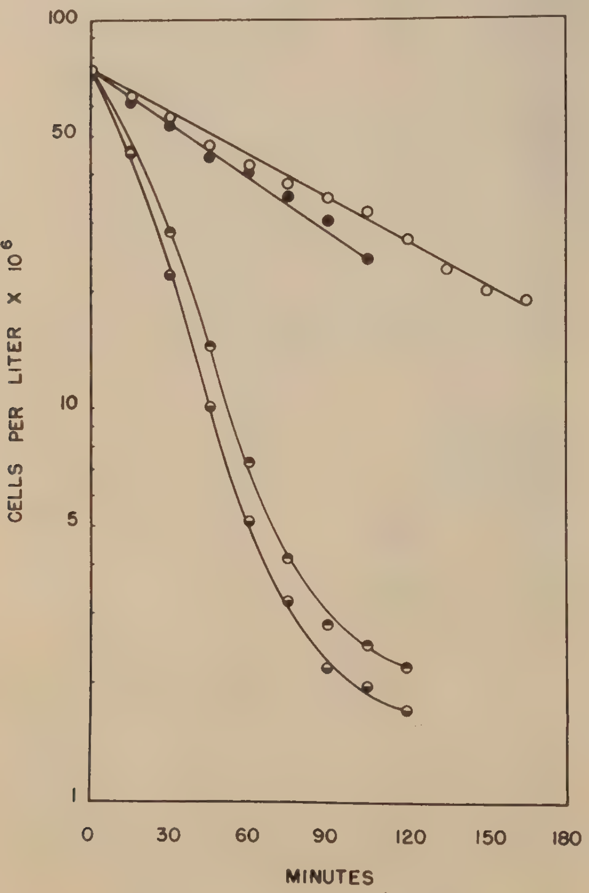

Figure 2. Rates of removal of unicellular phytoplankton from suspension by filter-feeding activity of the hard clam (Rice and Smith, 1958).
○ = Nannochloris; ● = Chlorella; θ = Nitzschia sp.; and ⊖ = Nitzschia closterium.

The numbers of diatoms in suspension have an effect upon the filtering rate of the hard clam (Figure 3). There is much similarity between the curves representing the removal of cells at the two intermediate population sizes. The curves re resenting the highest and the lowest population sizes, while being somewhat similar, are quite di ferent from the curves for the intermediate-size populations. Obviously, the number of Nitzschia closterium cells in the water does affect the rat at which the clam removes these diatoms and this would control the amounts of radionuclides that could enter the clam associated with the diatoms.

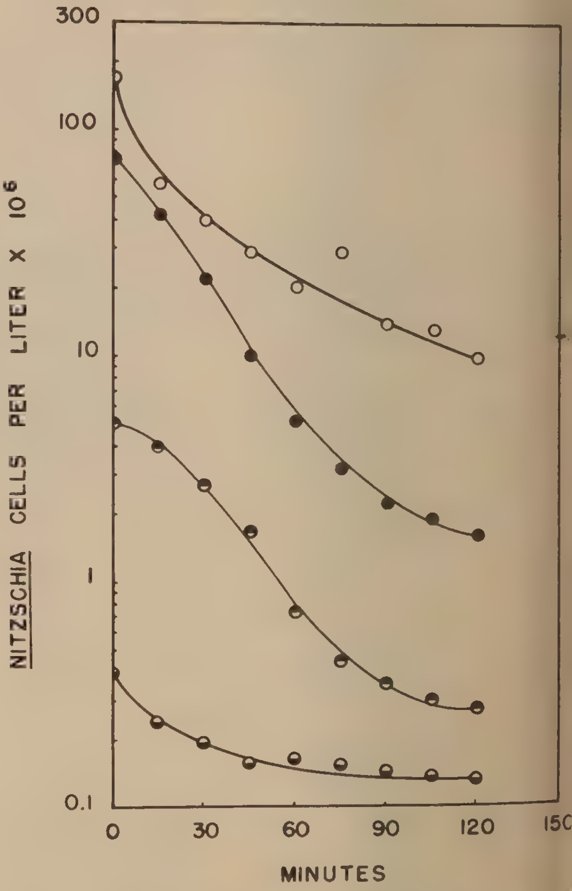

Figure 3. Effect of numbers of Nitzschia closterium cells on their rate of removal by the hard clam (Rice and Smith, 1958).

UTILIZATION OF PHYTOPLANKTON

Different species of phytoplankton that accumulate a radionuclide to the same level and are removed from the water with the same efficiency b a filter-feeding animal may not result in these animals becoming equally radioactive. This is du to all species of phytoplankton not being digeste with the same efficiency. Thus they cannot be equally important in the cycling of radionuclides in the ocean. One might expect a positive cor-

lation between the number of cells passing
rough the intestinal tract and the amount of
trient material assimilated by the tissues of
e filter-feeding animal, if digestion and uti-
zation of the ingested material occur. Con-
rsely, the lack of correlation would suggest
at no utilization of this ingested material oc-
rs. Oysters were fed Carteria, Skeletonema
statum, Chlamydomonas, and Chlorella labeled
th radioactive phosphorus (Floyd, 1952). A
od correlation was found between the number of
dioactive cells, and therefore the phosphorus-
in the gut of the oyster, and the radioactive
osphorus of the compounds of the adductor mus-
e when oysters fed on Carteria, Skeletonema,
d Chlamydomonas cells. However, there was no
rrelation when oysters fed on Chlorella (Figure
. Even though there were more radioactive Chlor-

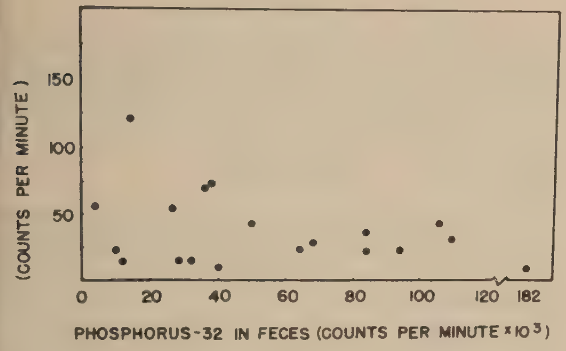

Figure 4. Inability of oysters to utilize Chlorella cells as shown by the lack of correlation between phosphorus-32 in the adductor muscle and that passing through the digestive tract (Floyd, 1952).

lla cells passing through the intestinal tract of
ome oysters, there was no additional accumulation
phosphorus-32 in the phosphorus-containing
mpounds of the adductor muscle. Accumulation
phosphorus-32 was followed in the adductor mus-
le of the oyster since it was believed that phos-
orus-32 could get into this tissue only from
etabolic processes. Marshal and Orr (1955) us-
g phytoplankton labeled with phosphorus-32 have
own that up to 90 per cent of diatoms and flag-
llates may be utilized by Calanus but that only
small percentage of Chlorella was available to
hese animals.

COMPARISON OF PHYTOPLANKTON AND WATER AS SOURCES OF RADIONUCLIDES

Some investigators are of the opinion that
he level a radionuclide reaches at equilibrium
n an animal will be the same whether or not the
adioactivity is obtained from water or from phy-
oplankton. In our opinion this may not be valid
n all instances for all radionuclides. One of
ur experiments with Artemia will demonstrate
his, but first it should be mentioned that Arte-
ia will live four to six months under the con-
itions employed in our laboratory. The experi-
ent was followed for 14 days, or about one-
ighth to one-twelfth of a lifetime, with no in-
ication that the Artemia obtaining radioactive
obalt from water would ever contain as much as
ther Artemia obtaining radioactive cobalt from
ood.

The accumulation of radioactive cobalt by Artemia from water was compared with accumulation from food consisting of Carteria cells (Figure 5).

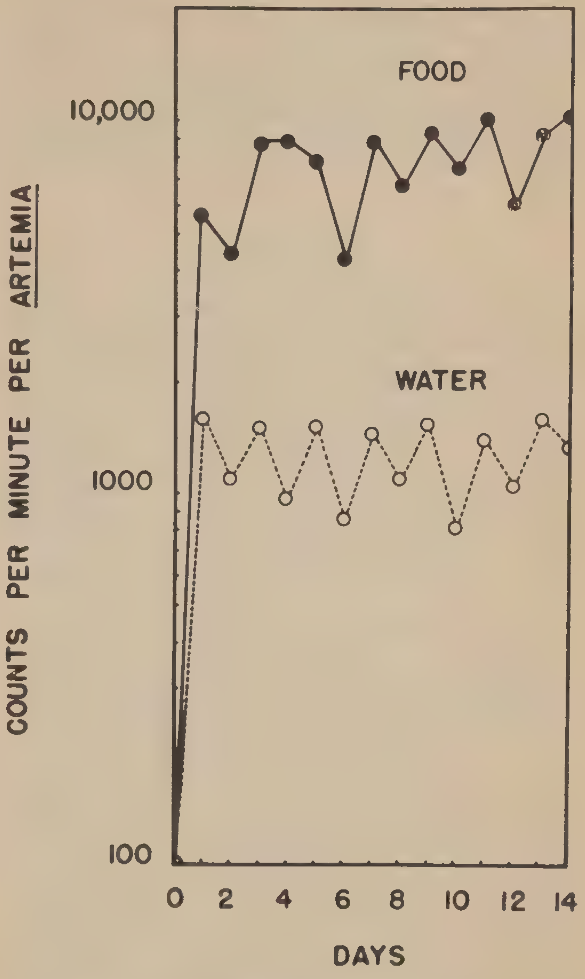

Figure 5. Comparison of accumulation of radioactive zinc by Artemia from food and water (Rice and Murdoch, unpublished data).

One group of 50 Artemia was transferred alternately between volumes of sea water culture medium every 24-hour period. One volume of medium contained radioactive cobalt, while the other volume contained 200 million nonactive Carteria cells per liter but no radioactivity. Another group of 50 Artemia was transferred alternately between volumes of nonactive medium, one volume containing 200 million radioactive Carteria cells. The Carteria cells had grown for two days in medium containing the same amount of radioactive cobalt as that in the radioactive medium used with the group of Artemia fed nonactive cells. This procedure made it possible to continue the experiment for 14 days since the Artemia in both groups were fed Carteria cells every other 24-hour period. One group of Artemia fed on Carteria labeled with radioactive cobalt, while the other group fed on nonactive Carteria and obtained radioactive cobalt by direct uptake from radioactive water.

Soon after the experiment was started and throughout the 14 days uptake was followed, there was a greater amount of radioactive cobalt in the animals obtaining their activity from *Carteria* cells. *Artemia* getting radioactive cobalt from algal cells contained 7.5 times as much as those getting radioactive cobalt from water. The important point here is that some small organisms, which may be important accumulators, may not live long enough to reach equilibrium when activity is from water. The rate then, and therefore the source of the isotope, will be the deciding factor in the eventual concentration reached in the organism.

DISCUSSION

The ecological role of phytoplankton in the sea has been known for many years, but it was only with the advent of radionuclides that it has been possible to delineate the utilization of many trace elements and the adsorption of elements on the surface of phytoplankton cells. It is now known that a large portion of many elements occurring in sea water are adsorbed on the surface of cells, that this portion in many instances may be larger than that portion necessary for metabolism, and that many essential trace elements occur in sea water in much higher concentrations than are needed for the growth of phytoplankton. Also, it has been shown that the particulate fraction of an element becomes associated with the cells at a faster rate than the ionic fraction.

The capacity of phytoplankton to accumulate large quantities of elements from sea water in a relatively short period of time is one of the most important factors making it so effective in the passage of radionuclides to higher trophic levels. In instances of acute pollution of sea water the radioactivity will be diluted to lower and lower concentrations with time. However, the rapid uptake by phytoplankton counteracts this dilution effect in that much uptake by cells occurs while the concentration of activity is still high. Since both fresh-water and marine phytoplankton possess this capacity of rapidly accumulating radionuclides, an excellent illustration of the rate of uptake by a natural population of phytoplankton is given by Foster and Davis (1956). They state that Columbia River plankton, consisting almost entirely of diatoms, appeared to reach equilibrium in about one hour after floating into the zone containing radioactive effluent from the Hanford reactors. This rapid uptake makes it possible for animals to accumulate considerable amounts of radioactivity by consuming the phytoplankton when otherwise they would not be able to acquire as much activity from the water. Even in many of those instances where there is no large concentration of the radionuclide in phytoplankton, they would still be very effective in the cycling of radionuclides.

The importance of phytoplankton in passing radionuclides to higher trophic levels is not easy to assess. Many factors, interacting to varying degrees, determine the effectiveness of phytoplankton, at any one location and at any specific time, in concentrating radionuclides and serving as a source of radioactivity for animals in the area. In the oceans many factors are in operation replenishing nutrients utilized for phytoplankton growth. Simultaneously, other factors are tending to reduce the standing corp of phytoplankton cells. These conditions may result in a rapid division of cells without any large variation in the number of cells composing the standing crop. In laboratory investigations the classical culture technique of growing cultures in confined volumes of medium has subjected cells to more drastic conditions. To grow algae under conditions that more nearly simulate growth in a natural environment, a continuous culture system has been devised. Bacteriologists have used a similar culture method and called it a "chemostat." Both Taylor (1960) and the author are using such a system for growing algae. With this continuous culture method it is possible to maintain a constant population of cells in the culture container and a desired level of nutrients in the water. This insures that cells will grow under more nearly constant conditions similar to those occurring in nature. Data collected by this method on uptake and accumulation of radionuclides by populations of phytoplankton will be published by the author in the near future.

SUMMARY

The importance of phytoplankton in passing radionuclides up the food web depends upon the number and amount of radionuclides accumulated, the length of time these radionuclides are retaine by the phytoplankton, the size of the phytoplankto cells and the number of cells present in the water and the efficiency of digestion of the cells by filter-feeding animals.

1. It has been shown both in the laboratory and under field conditions that phytoplankton accumulate a large number of elements from sea water and are, therefore, very important in the removal of radionuclides.

2. The availability of a radionuclide is dependent to a large extent upon its physical stat in sea water. Radionuclides in the colloidal and particulate states are accumulated as well as radionuclides in the ionic state. Actually cerium 144 in the particulate state was accumulated more rapidly than cerium-144 in the ionic state.

3. The accumulation of a radionuclide by phytoplankton depends both upon the total amount of the element present in sea water and the quantities of other metabolically similar elements.

4. All species of phytoplankton will not be equally important in the cycling of all radionuclides in the oceans, based on their capacity to concentrate radionuclides.

5. For phytoplankton to be of importance in the passage of radionuclides up the food web it is not only necessary that the cells accumulate the radioactivity, but also that it be retained for considerable periods of time. Division of radioactive phytoplankton in nonactive water results in a 50 per cent reduction of activity per cell with each division. This has been referred to as "biological dilution." The amount of phosphorus-32 exchanged by *Nitzschia* cells varies with the concentration of phosphorus in the medium in which the cells were grown, the physiological condition of the cells, and the length of time the cells were grown in medium containing phosphorus-32.

6. Even though phytoplankton remove large amounts of radionuclides from sea water, the amoun that can be passed up the food web will vary with cell size and total numbers of cells in the water since these are among the more important factors affecting the efficiency of the filtering mechanis of filter-feeding animals.

7. Different species of phytoplankton that accumulate a radionuclide to the same level and

e removed from the water with the same efficiency by a filter-feeding animal may not result these animals becoming equally radioactive. is is due to all species of phytoplankton not ing digested with the same efficiency.

8. Radioactive cobalt was concentrated to her levels in Artemia when these animals fed on radioactive Carteria cells than when the ivity came from the water.

9. It was concluded that phytoplankton are portant in the cycling of radionuclides in the eans.

ACKNOWLEDGMENTS

This paper was prepared under a cooperative eement between the U. S. Atomic Energy Comssion and the U. S. Bureau of Commercial Fishles.

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REVIEW OF ZINC IN ECOLOGY

T. R. Rice

Reprinted from PROCEEDINGS OF THE FIRST NATIONAL
SYMPOSIUM ON RADIOECOLOGY. 1961
Edited by Vincent Schultz and Alfred W. Klement, Jr.

REVIEW OF ZINC IN ECOLOGY

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INTRODUCTION

Zinc has been shown to be an almost univer- l constituent of living matter and is now con- dered essential for the growth and normal develop- nt of most microorganisms, plants, and animals. has been estimated that zinc represents 0.004 per nt of the earth's crust and is twenty-fifth in der of abundance, certainly far scarcer than less miliar elements such as zirconium, vanadium, anium, and strontium. It is now necessary that e role of zinc in the terrestrial, fresh-water, d marine environments be delineated since zinc- has been shown to be present in all three. nc-65 occurs in these environments not as a oduct of the fission of uranium or plutonium t rather as an induced radionuclide. Atoms many stable elements, such as sinc, in and/ around nuclear device fittings or in sea water the vicinity of a neutron flux, occurring at e time of a nuclear detonation, capture neutrons d become radioactive. Some of these induced dionuclides are swept in the mushroom-shaped oud that forms following a nuclear detonation d are dissipated over a large portion of the rth's surface as fallout. Thus, all three of e above environments have received zinc-65 rough fallout. Of the zinc-65 falling upon the rrestrial environment, some is leached from the il and carried by rain water into rivers and entually into the oceans. Another source of nc-65 to the fresh-water environment results om the use of river water as a coolant for nu- ear reactors. Subsequent use of this water for rigational purposes has resulted in some zinc- finding its way to the terrestrial environment.

Algae and molds have been used most widely studies on the requirement of zinc for the owth of microorganisms. The essentiality of all amounts of zinc for the laboratory culture many species of flagellates has been in- stigated (Ondratscheck, 1941). Also, the green ga, *Chlorella pyrenoidosa*, has been found to quire the inorganic micronutrient zinc (Myers, 51). In molds zinc has been shown to be essen- al for the optimum growth of such species as *pergillus niger*, *Phycomyces blakesleeanus*, and *zopus nigricans*. Its role is catalytic, ucose being utilized more completely in its esence (Waksman and Foster, 1938). As early as 59 Raulin demonstrated that the growth of *A. ger* was stimulated when small amounts of zinc e added to the growth medium. These observa- ons were confirmed in two papers by Javillier 908) who also estimated the optimum concentra- on of zinc in the nutrient medium. Wassiljew 935) demonstrated that the effect of zinc was t the same for biochemically different strains *A. niger*, and suggested a characterization of *niger* strains based on their reactivity to nc.

The value of zinc as a plant nutrient is not new discovery even though the extensive use of nc salts as a nutrient for crops dates only from out 1931 (Camp, 1945). Javillier as early as 12 recommended the use of zinc as a fertilizer r corn and some other crops. At about the same me Maze (1914) determined by water culture thods that zinc was necessary for the growth of corn, though his findings, like those of Javillier, were not well accepted. In the period from 1931 to 1936 zinc became established as both a plant nutrient and a valuable fertilizer and spray material. Zinc deficiency symptoms have been described for deciduous fruits (Chandler et al., 1931, 1932), pecans (Alben et al., 1932; Finch and Kinnison, 1933), corn (Barnette and Warner, 1935; Barnette et al., 1936), tung (Mowry and Camp, 1934), and numerous other crops. Symptoms now known to be associated with zinc deficiency in many plants were well known long before their cause was determined. Skoog (1940) found that zinc deficiency resulted in a low auxin content of the leaves and a very low content in terminal buds and stems. Stem growth could be increased by supplying indole acetic acid, but this did not nullify the requirement for zinc. Plants apparently vary greatly in their zinc requirements and also in their ability to obtain zinc from a given soil.

Developments in the relation of zinc to the metabolism of animals have been no less stimulating. The production of uncomplicated zinc deficiency in experimental animals and the discovery of zinc in purified enzymes and hormones have given unmistakable proof of the indispensability of zinc in many animals. Mendel and Bradley (1906) in studies on the occurrence of zinc in some invertebrates, observed considerable amounts of this element in the liver and blood of the snail, *Sycotypus*. They found that the respiratory pigment hemosycotypin was extremely rich in zinc and suggested that zinc was an essential constituent of this pigment. The zinc content of herring testes and milt was correlated with their seasonal sexual activity by Bertrand and Vladesco (1921).

Several attempts to demonstrate an essential function for zinc in mammalian nutrition, made during the 1920's by Bertrand and Benson (1922), McHargue (1926), and Hubbell and Mendel (1927) met with only limited success. The diets employed were so deficient in other essential nutrients, especially vitamins, that even with added zinc the experimental mice and rats survived only for a short time. Todd et al. (1934) produced conclusive evidence that zinc is essential for growth in the rat. Diets low in zinc, but better supplied with other dietary essentials, were subsequently produced which disclosed the profound importance of zinc for growth in both rats and mice.

The isolation and purification of an enzyme, carbonic anhydrase, containing 0.33 per cent zinc as part of its molecule, by Keilin and Mann (1944) offered the first concrete explanation of a mode of action of this element. Zinc was demonstrated to be essential to the mechanism of action of this enzyme, which catalyzes the dehydration of carbonic acid and participates in the elimination and incorporation of carbon dioxide. The recent discovery of zinc in many highly purified enzymes (Vallee, 1955) has revealed the diversity of its function in protein and carbohydrate metabolism.

Zinc does not occur in an uncombined state in nature so the discovery of brass undoubtedly was a fortunate accident of an ancient metal-smith who melted copper in the presence of zinc ore and carbon. The name, zinc, comes from German and means "of unknown origin." The Chinese probably were the first to extract zinc metal, though its first description in 1597 by an occidental traveler, Liborius, related that it was observed in India. Zinc usually occurs in combination with sulfur or oxygen. The ores of zinc are widely distributed, the principal one being the zinc sulfide, sphalerite. The element has the atomic number 30 and atomic weight 65.38. There are several radioisotopes of zinc, of which zinc-65, with a half-life of 245 days, has been most widely used for biological studies. The rapid reaction of zinc with negatively charged groups may be pertinent to its significance in biology, where it is accumulated to higher levels than many elements more abundant in the environment.

Difficulties encountered in the analytical determination of zinc at levels existing in plants and animals and equal difficulties in freeing water and reagents from contamination with zinc have been deterrents of zinc research. Thus, for many years it was not known whether many quantitative procedures were accurate or if they merely gave reproducible results. The serious limitations of earlier methods must be kept clearly in mind in the evaluation of the findings obtained with these procedures. With the availability of radioactive zinc it became possible to determine and to locate operations which were particularly susceptible to error. For the determination of 1 to 100 micrograms of zinc, separation of zinc from other substances is necessary. The only suitable separations are dithizone extractions in the presence of various masking agents, anion exchange resin elution with hydrochloric acid, and certain sulfide precipitations (Margerum and Santacana, 1960).

Once zinc has been isolated by the dithizone separation procedure, it can be quantitatively determined by titration with dithizone, by the titration of zinc dithizonate with bromine, by the spectrophotometric mixed color method, or by the spectrophotometric single color method. The spectrophotometric methods are superior to the titrimetric methods. When zinc is isolated by the use of an anion exchange column it can be determined with dithizone or with a water-soluble color reagent such as Zincon. Zincon has been useful in animal and plant analyses where many impurities are known to be absent, but it should be used with caution.

Among the many questions for which answers must be obtained, if they are not now available, to better understand the cycling of zinc-65 in the terrestrial, fresh-water, and marine environments are the following: (1) does zinc-65 remain in the ionic or soluble state, so that it can percolate through the soil to the roots of plants, (2) does it remain in solution in fresh water and sea water where it will be available for uptake by plants and animals or is it readily adsorbed on surfaces, (3) what are the factors regulating the uptake of zinc by plants from soil and water, (4) what plants absorb zinc and to what levels, (5) is zinc-65 biologically or chemically lost from plants, (6) in what portions of plants is zinc stored, (7) can zinc be efficiently assimilated by animals from plant material, (8) do animals concentrate zinc to high levels, and if so, in what tissues, (9) does zinc-65 have a long biological half-life in animals, and (10) is zinc-65 as readily available to animals from water as from food in the aquatic environment?

TERRESTRIAL ENVIRONMENT

Zinc-65 in the terrestrial environment will follow the same path as stable zinc from environment to organisms and back to the environment. Plant growth requires the continuous net removal of zinc ions from the soil into the plants and a steady metabolic immobilization of zinc by the plant. It is obvious that zinc-65 must move to the vicinity of the root to be taken up by a plant. Next, it must move from the vicinity of the root into the root; and finally, to occur in the plant proper, must move from the root to the top of the plant. In addition to uptake of zinc-65 by the root, absorption can occur through the leaves. Both terrestrial and aquatic organisms can obtain zinc from food and water. Whether or not zinc is as readily available and can be obtained in as large quantities from drinking water as from food by terrestrial animals remains to be determined.

The amount of zinc-65 accumulated by farm produce from Columbia River water used for irrigational purposes is associated with the natural zinc deficiency of the soil (Davis et al., 1958). Extensive areas of zinc-deficient soils have been located in different parts of the world. Some soils contain insufficient total or available zinc to meet the requirements of plant growth. Zinc-deficient soils within the boundaries of the United States have been reported in Florida, Georgia, Texas, Louisiana, Arizona, Michigan, Utah, and Washington (Beeson, 1945). The use of zinc-containing sprays and fertilizers has become standard agricultural practice on these soils, usually with spectacular improvement of growth and productivity of plants (Underwood, 1956) Now, the important question arises as to whether or not there would be a greater uptake of zinc-65 by plants growing on zinc-deficient soils than would occur if the soil contained adequate levels of zinc.

Direct foliate absorption through the leaves of sprinkler-irrigated crops has been shown to be an important pathway in the uptake of zinc-65 (Perkins et al., 1960). During the summer of 1959, samples of produce were collected from two farms irrigated with Columbia River water about 30 miles downstream from the Hanford reactors, one of which used sprinkler irrigation and the other ditch irrigation. Although it was not possible to obtain all the same crops from the two farms for comparison, it was apparent that levels of zinc-65 were generally higher in crops from the sprinkler-irrigated farm.

Radioisotope studies have given the needed sensitivity to measure reactions of zinc with soil minerals under concentrations approximating soil situations. The data obtained indicate that available zinc is reduced to low levels by absorption on soil minerals (Thorne and Wiebe, 1957). Lattice sites occupied by magnesium have a high adsorption of zinc. A reduction in the zinc content of plants has resulted from excessive liming of the soil (Rogers and Wu, 1948). Also, zinc deficiencies frequently have been observed in soils with a high phosphate content (Thorne and Wann, 1950; Winters and Parks, 1955). Morrill (1955) added varying amounts of phosphate to solution cultures containing 3.6 parts per million of zinc labeled with zinc-65 and found that during short periods, uptake of zinc by corn seedlings was significantly reduced by phosphate throughout the pH range from 6.5 to 8.2. A consideration of the solubility characteristics of zinc phosphate indicates that zinc deficiencies cannot be accounted for by the direct precipitation of zinc by phosphate ions. There is a distinct possibility, however, of strong adsorption of zinc on the surfaces of phosphate minerals in soil.

Zinc-65 must be in a certain chemical form when added to some soils for a very large amount to be absorbed by plants growing in these soils. It is now known that zinc deficiency in critrus is common wherever this crop is grown and that soil applications of common zinc salts are

ally not effective in alleviating the deficiency
ewart and Leonard, 1956). These investigators
e tests to determine whether chelated forms of
c were more effective as a plant nutrient than
rganic forms. In a preliminarv trial, zinc
ylenediaminetetraacetic acid (ZnEDTA) and zinc
fate labeled with zinc-65 were applied to citrus
dlings growing in four different types of soil.
soils used had a wide range of chemical and
sical properties, but were typical of those
nd in the citrus growing areas of Florida where
c deficiency is common. The St. Lucie soil is
ine white sand with an exchange capacity of
milliequivalent or less per 100 grams. The
kwood is a heavy calcareous soil that usually
an exchange capacity of 20 milliequivalents
above. The Lakeland and Blanton soils are
ermediate in their properties. The Lakeland
e sand has an exchange capacity varying from
or three and the Blanton from three to six
liequivalents. For this experiment, pots
taining 4.5 pounds of soil were used. Grape-
it seedlings were transplanted to the pots
the zinc treatments were applied only after
plants had become established and the roots
e well distributed in the soil. Zinc sulfate
zinc ethylenediaminetetraacetic acid (ZnEDTA)
atments were labeled with 20 microcuries of
c-65 and applied in approximately 300 milli-
ers of solution at the rate of 40 pounds of
c per acre. Plants were harvested 11 days
er the treatment and measurements were made
the ashed tissue.

Much larger amounts of zinc-65 were taken
from the zinc ethylenediaminetetraacetic acid
n from the zinc sulfate in all the soils ex-
t the Parkwood (Table 1). The greatest differ-
e in uptake between the two sources of zinc
in the St. Lucie fine sand, and the least
ference was in the Parkwood soil. The uptake
zinc from zinc ethylenediaminetetraacetic acid
these soils was inversely related to their
hange capacities. Also, Bergh (1952) has shown
t of the zinc-65 remaining in the soil 36 days
er being sprayed with zinc sulfate containing
c-65 none had penetrated to a deeper layer than
to 21 centimeters and only 1.04 per cent of
s was recovered from the plants.

Table 1. Uptake of zinc-65 from $Zn^{65}SO_4$ and from Zn^{65}EDTA by grapefruit seedlings growing in four different soil types (after Stewart and Leonard, 1956).

oil	Exchange capacity (milliequivalents) per 100 grams)	Zn^{65}EDTA (counts per minute per gram)	$Zn^{65}SO_4$ (counts per minute per gram)
Lucie	1	784	17
eland	2 to 3	113	8
nton	3 to 6	77	11
kwood	20	36	28

Plants apparently vary greatly in their zinc
uirements and also in their ability to obtain
c from a given soil. Certain plants take up
c in quantities very far above the average
ntity for "normal" plants. These are the
nts which would probably contain the largest
ntities of zinc-65 when this radionuclide oc-
red in the soil. There is the classical case
a violet, Viola calaminaria, taking up huge
ntities of zinc from soils in the zinc in-
trial region of Belgium (Robinson and Edington,
5). In this instance there was some question
zinc dust contamination. Rogers, Gall, and
nette (1939) reported 714 parts per million of
c in Diodella and 585 in foxtail growing in Florida on a sandy soil in which corn showed a zinc deficiency. Lyman and Dean (1942) found 144 and 158 parts per million of zinc in the tips of the leaves of the pineapple plant. Hibbard (1943) observed 162, 187, and 208 parts per million in specimens of Malva rotundifolia grown in California. The amount of zinc taken up by a plant may be proportional to the amount in the soil since ragweed plants growing on a zinc mineral outcrop near Zinc, Arkansas, had accumulated 3,800 parts per million of zinc and tobacco plants growing on an unlimed soil in a galvanized Lysimeter tank took up as high as 1,540 to 2,000 parts per million of zinc as determined in the whole plant above ground (Robinson and Edington, 1945).

The distribution of zinc in plants has been followed with zinc-65. Both autoradiograms and radioactivity measurements have been used to determine the relative accumulation of zinc-65 in the various parts. Stout et al. (1948) found a greater proportion of zinc in the seeds and conducting tissues of tomato plants than in the pulp of fruits. Zinc was also retained in abscission tissue. Bergh (1950) observed that roots of Pisum saccharatum plants accumulated the most zinc-65 from Hoagland's solution and that old blades contained the least. A larger proportion of the zinc in the pea, shell, and blade was water soluble than in the root. The insoluble zinc appeared to be associated with the protein fractions. Davis et al. (1958) have followed the uptake and translocation of radionuclides by bean plants from undiluted reactor effluent water. The uptake and distribution of zinc-65 in plants grown in six liters of effluent solution for 14 days are listed in Table 2. The average concentration of zinc-65 in the solution was 1.28×10^{-5} microcuries per milliliter and the solution was changed three times during the experiment.

Table 2. Zinc-65 in bean plants cultured for 14 days in reactor effluent containing plant nutrients (after Davis et al., 1958).

Part of plant	Zinc-65 (per cent)
Leaves	3.3
Steams	1.5
Roots	66.2

There is evidence that the distribution of zinc in a plant may be influenced by the environment in which the plant is grown (Biddulph, 1953). Plants grown in solutions containing high concentrations of phosphorus resulted in zinc being precipitated along the veins. Under high iron nutrition less zinc was precipitated along conducting tissues, apparently because the level of soluble phosphate in the soil was reduced by precipitation with iron. When plants were grown in low concentrations of phosphate, zinc was distributed rather uniformly throughout the leaf and was not concentrated along the veins. Zinc is not commonly retranslocated from older leaves to younger leaves as the plant grows. It has been shown that labeled zinc present in the roots and main axis of a plant, Trifolium subterranium L., was almost completely replaced by stable zinc absorbed during the next 26 days (Riceman and Jones, 1960).

Zinc-65 has been followed from Columbia River water used for irrigational purposes through plants and animals to man (Perkins and Nielsen, 1959). This has been possible even though it was present at a concentration far below recommended maximum permissible limits in regard to a health hazard. The farm-produce and animal samples considered here were obtained from an irrigation project about 30 miles downstream from the Hanford reactors. Zinc-65 was found in all the farm produce sampled

Partial maximum permissible concentrations have been calculated for radionuclides which may occur in the oceans (Pritchard, 1960). The concentration of zinc-65 which can occur in sea water when such disposal is of only local concern is 1 x 10^{-7} microcuries per gram while 3 x 10^{-9} microcuries per gram can occur when whole populations may be involved. Seafood can contain as much as 3 x 10^{-4} microcuries per gram when it os of only local concern while 1 x 10^{-5} microcuries per gram can occur when whole populations are involved. These values apply to long-term large area average concentrations. It is believed that short-term and very localized concentrations may exceed these values without introducing any undue risk.

Sea water contains much less zinc than would be expected, based on an estimate of the amount of zinc supplied to the ocean from weathering of rocks (Rankama and Sahama, 1950). Krauskopf (1956) has suggested that precipitation of sulfides might control the concentrations of zinc in sea water and has shown that sea water is under-saturated with respect to any insoluble compounds of zinc that might form from the ions normally present in aerated sea water. Reported values for the concentration of zinc in sea water range from 1.2 to 30 micrograms per liter. The zinc values given by a number of investigators are summarized in Table 7.

Table 7. Reported concentrations of zinc in sea water.

Geographical location	Zinc in micrograms per liter	Reference
Tokyo Bay, Japan	2.8 to 11.7	Morita (1950)
Coast of Honshu, Japan	7.0	Kuroda (1940)
Western Baltic	5.0 to 30.0	Wattenburg (1943)
Coast of Sweden	14.0	Noddack and Noddack (1940)
Coast of Finland	4.5 to 23.0	Buch (1944)
Galveston, Texas	7.5	Bodansky (1920)
Redfish Bay, Texas	6 to 8	Parker (1961)
Beaufort, N. Carolina	1.2 to 19.6	Chipman et al. (1958)
Coast of Great Britain	9.0 to 21.0	Black and Mitchell (1952)

Since zinc-65 in sea water can either be lost to suspended or bottom sediments or taken up by the biota, rates at which these losses occur are of importance. In addition to rates, the amount of zinc-65 removed from the water by each process depends upon the total capacity of each to hold this radionuclide. Parker (1961) has shown that a huge reservoir of zinc is held in the top few centimeters of the sediment. It is obvious that waters which are highly turbid favor deposition of wastes.

Also, ocean waters receiving run-off from land, where leaching of certain clays has occurred, are particularly suitable for exchange reactions and will in time become part of the bottom sediments. There is no doubt that a large portion of any zinc-65 added to sea water will eventually become associated with the bottom sediments.

The occurrence of zinc-65 in plant and animal life following nuclear explosions at the Eniwetok Proving Ground in the Pacific has been followed (Lowman et al., 1957; Lowman, 1960). In plankton collected six weeks after contamination, zinc-65 was the radionuclide present in greatest abundance. In fish liver samples collected from Eniwetok Lagoon in September 1956, approximately six weeks after the test series, zinc-65 contributed 47 per cent of the total radioactivity. Zinc-65 was also the principal radionuclide found in tuna samples taken in the open sea near the test site during the test period in the summer of 1958. In these samples, zinc-65 contributed 81 to 91 per cent of the total radioactivity in five different organs. The terns, or sea swallows, at the Eniwetok Proving Ground also contained zinc-65 in their organs and tissues. Except during the time interval shortly after detonation, almost all of the radioactivity in these birds was due to zinc-65. It should be noted that the food of these terns is almost exclusively of marine origin. The high percentage of zinc-65 in these organisms after the fission products have all but disappeared indicates the biological importance of zinc and its low turnover rate.

That marine organisms can concentrate many elements occurring in sea water in extreme dilution is well known. Analyses of marine plants and animals have shown that the concentration of zinc in them exceeds the concentration in sea water by 1,000 times or more. The zinc content of some marine plants and animals in relation to the surrounding sea water is listed in Table 8.

The accumulation of zinc-65 by phytoplankton cells from water occurs at a very rapid rate (Boroughs et al., 1957). When carrier-free zinc-65 was added to a new culture of *Nitzschia* cells

Table 8. Zinc content of some marine organisms in relation to the surrounding sea water.

Organism	Zinc in organism (milligrams per kilogram)	Zinc in sea water (milligrams per kilogram)	Concentration factor over water	Reference
Algae (sea weeds)[1]				
Pelvetia canaliculata	21	.0210	10^3	Black and Mitchell (1952)
Ascophylum nodosum	29	.0210	1.4 x 10^3	Black and Mitchell (1952)
Fucus vesiculosus	24	.0210	1.1 x 10^3	Black and Mitchell (1952)
Mollusca[1]				
Oyster (*Crassostrea virginica*) Milford, Connecticut	3174	.0188	1.7 x 10^5	Chipman et al. (1958)
Oyster (*Crassostrea virginica*) Beaufort, North Carolina	1171	.0046	2.5 x 10^5	Chipman et al. (1958)
Sea butterfly (*Limacina* sp.)	42	.0014	3 x 10^4	Ketchum and Bowen (1958)
Squid (*Ommastrephens* sp.)	24	.0014	3 x 10^4	Ketchum and Bowen (1958)
Crustaceans[2]				
Shrimp (*Penaeus aztecus*)	45	.0080		Parker (1961)
Crab (*Callinectes sapidus*)	46	.0080		Parker (1961)
Barnacle (sp. not given)	36	.0080		Parker (1961)
Fish[2]				
Mullet (*Mugil cephalus*)	130	.0080		Parker (1961)
Pinfish (*Lagadon rhomboides*)	113	.0080		Parker (1961)
Silverside (*Mendidia* sp.)	51	.0080		Parker (1961)
Killifish (*Fundulus similis*)	29	.0080		Parker (1961)

[1] Wet weight basis.

[2] Dry weight basis.

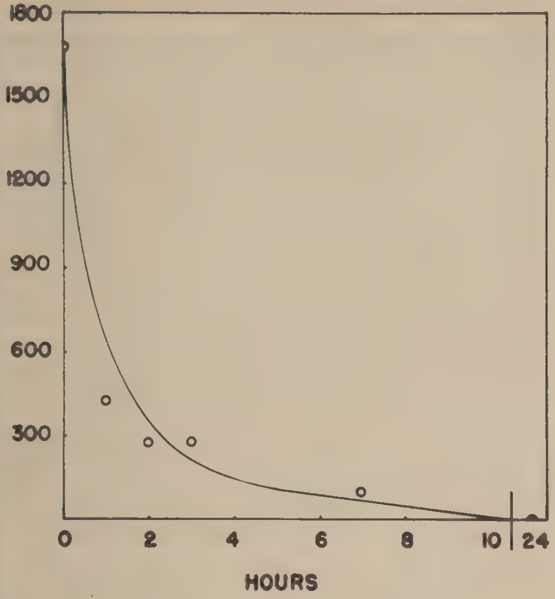

Figure 1. Reduction of zinc-65 level in medium due to accumulation by *Nitzschia* cells (after Boroughs et al., 1957).

t was removed from the water so rapidly that fter 24 hours essentially no radioactivity reained in the medium (Figure 1). The cells were llowed to remain in this medium for 15 days, uring which time they divided ten times. Since o zinc-65, and presumably no stable zinc, was vailable in the medium during this time, the ells could only continue to divide the zinc mong an ever-increasing number of cells until, fter ten divisions, it would require zinc from 12 cells to equal that originally present in one ell. What can be said about the zinc requirements f these cells? It is obvious that zinc is accuulated far in excess of any immediate metabolic eed.

An experiment was conducted to determine the ffect of a reduction in the available zinc on he growth of phytoplankton. A chelating agent, thylenediaminetetraacetic acid (EDTA), was added o medium containing *Chlamydomonas*. By using inc-65 as a tracer it was found that the cells emoved only about 20 per cent of the zinc from he medium in four days. Every four days the ells were transferred to new medium containing inc-65 and EDTA. At the end of 64 days there as no indication that this fivefold reduction n the availability of zinc had any effect on the ivision rate or the production of new cells. If inc is required for growth of this species of hytoplankton, then the amounts occurring in natral sea water must be far in excess of its needs. t has been shown by Bachman and Odum (1960) that n marine seaweeds zinc is taken up in proportion o the gross oxygen production and accumulated in roportion to the net oxygen production.

Above the first trophic level the rate of ccumulation may be influenced by whether the upake of the radionuclide is occurring from the ater or from the food of the animal. Although n some instances both water and food may serve imultaneously as a source of zinc, it has been ssumed that the eventual concentrations of zinc-5 in the tissues of an animal would be the same hether accumulation is from only food or water. his may not be true in all animals.

We have conducted an experiment to determine the accumalation of zinc-65 by the brine shrimp, *Artemia salina*, from water as compared with the accumulation from food consisting of algal cells. In this experiment a group of 50 *Artemia* was transferred alternately between two 200 milliliter volumes of sea water culture medium every 24-hour period. One volume of medium contained 32.44 microcuries of zinc-65 as zinc chloride per liter, and the other volume contained 200 million nonactive *Carteria* cells per liter but no zinc-65. A new volume of labeled medium and a new volume of non-labeled medium containing non-labeled cells from a two-day-old culture of *Carteria* were alternated for each 24-hour period of time.

Another group of 50 *Artemia* was transferred alternately after each 24-hour period between two 200 milliliter volumes of non-labeled medium, one volume containing 200 million zinc-65 labeled *Carteria* cells per liter. The *Carteria* cells had been grown previously for two days in medium containing 32.44 microcuries of zinc-65. During this time the cells removed practically all of the zinc-65 from the medium. *Carteria* cultures were started every other day so that a two-day old culture could be used for every other 24-hour period. This procedure made it possible to continue the experiment for 22 days since the *Artemia* in both groups were fed *Carteria* cells every other 24-hour period. One group of *Artemia* fed on *Carteria* labeled with zinc-65, while the other group fed on non-labeled *Carteria* and obtained zinc-65 by direct uptake from labeled water.

An additional seven *Artemia* were kept individually in four milliliters of medium contained in a five milliliter glass vial and were treated the same as one of the above groups of *Artemia*. Another seven *Artemia* were treated the same as the other of the above groups. Radioactive zinc in these two groups of seven *Artemia* was measured on individual animals at the end of each 24-hour period, and an average of the zinc-65 per individual from each group is shown in Figure 2. Zinc-65 in the

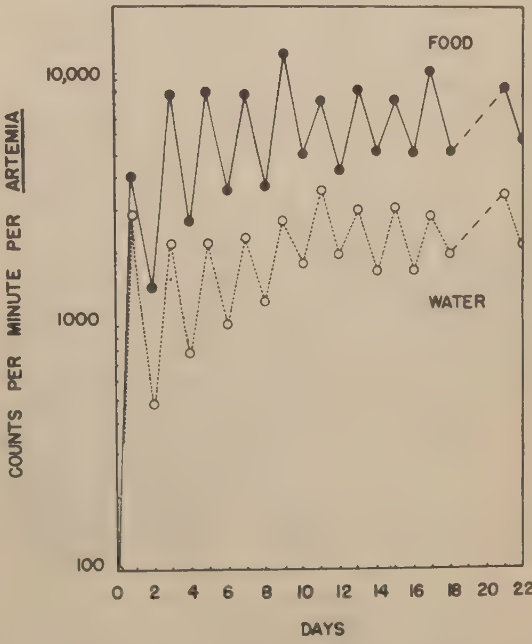

Figure 2. Comparison of accumulation of zinc-65 by *Artemia* from food and water (Rice and Murdoch, unpublished data).

50 Artemia in each of the first two groups was not measured until the end of 22 days, at which time the animals were weighed and a concentration factor was calculated for both males and females.

Artemia feeding on labeled Carteria contained more zinc-65 on the average throughout the entire experiment than did Artemia obtaining zinc-65 by direct uptake from the water. After 22 days Artemia feeding on labeled Carteria contained enough zinc-65 to give 5,572 counts per minute per animal while Artemia kept in labeled medium contained only 2,131 counts per minute. There was more zinc-65 in Artemia when removed from labeled medium or from medium containing labeled Carteria cells than the following day when the concentrations were reduced due to a loss of zinc-65 from the Artemia to the non-labeled medium. Also, a loss of zinc-65 from Artemia, which had been feeding on labeled Carteria cells, occurred as a result of excretion of undigested or partially digested cells.

The concentration factors for both males and females were determined. Male Artemia had a concentration factor of 76, while the female concentrated zinc-65 125 times over amounts in the medium. Radioactive zinc in Artemia which fed on labeled algae was 2.6 times as high as that in Artemia getting zinc-65 from the water. Therefore, it can be considered that these animals concentrated zinc-65 2.6 times over that of animals getting zinc-65 from water.

Some small animals may be good accumulators of zinc but might not live long enough to reach a state of equilibrium with the radioactive zinc in the water. The normal life span of Artemia in the laboratory is four to six months. This experiment ran for 22 days and there was no indication at that time that the Artemia getting the zinc-65 from water would ever contain as much zinc-65 as the Artemia getting it from food. In this case the rate of accumulation, and hence the source of the zinc-65, would determine the eventual concentration of zinc-65 in the animal.

Other organisms also take up zinc from the water very rapidly. Chipman et al. (1958) have shown that the separated gills of oysters (Crassostrea virginica) immersed in sea water containing zinc-65 reached a concentration factor over the water of 1,679 in 48 hours. There have been reports in the literature on the occurrence of zinc-65 in oysters from Chesapeake Bay (Murthy et al., 1959) presumably as the result of fallout, and from the coast of Washington (Perkins et al., 1960; Watson et al., 1961) as the result of effluent water from the Hanford reactors. The concentration of zinc-65 in oysters grown in Willapa Bay, Washington, the closest commercial oyster-producing area north of the Columbia River, appears to be substantially higher than in oysters from other areas. However, this higher concentration is not significant in terms of a radiological health hazard. The amount of oysters from Willapa Bay which one must eat in order to obtain the maximum permissible body burden of zinc-65 is given in Table 9. It should be stressed that these values are for sustained consumption and that the maximum permissible body burden associated with these rates will be reached only if intake is continuous for three years or more (Foster and Junkins, 1960).

The rate of accumulation of zinc-65 by any specific marine organism will probably not be the same at different seasons of the year and at different stages of the life history. Many factors, physical as well as biological, will act together to influence rates of accumulation. Figure 3 illustrates the accumulation of zinc-65 by a blue crab (Callinectes sapidus) and the effect of molting on this accumulation. In this experiment there was a rapid and continuous accumulation of

Table 9. Amounts of oysters from Willipa Bay, Washington, which must be eaten to obtain the maximum permissible body burden (after Foster and Junkins, 1960).

Premise	Sustained consumption rate to give exposure of premise
Occupational exposure - Handbook 69	700 pounds per week
Person in the neighborhood of controlled areas[1]	70 pounds per week
Suggested International Commission on Radiological Protection apportionment for genetic dose[2]	7 pounds per week
Doubling of natural background[3]	14 pounds per week

[1] Taken as 0.1 of values recommended in National Bureau of Standards (1959) Handbook 69 (National Committee on Radiation Protection, 1959).

[2] Taking 0.01 of the Handbook 69 values as equivalent to an exposure of 1.5 rem to the gonads in 30 years. It should be noted that the International Commission on Radiological Protection apportionment for genetic reasons assumes that the entire population is exposed at this level. The oysters in this case contribute to only a very small fraction of the total population.

[3] Assumes that a continuous intake rate of 2.2 microcuries per day results in 5 rems per year to the body and that the natural background is 100 millirems per year.

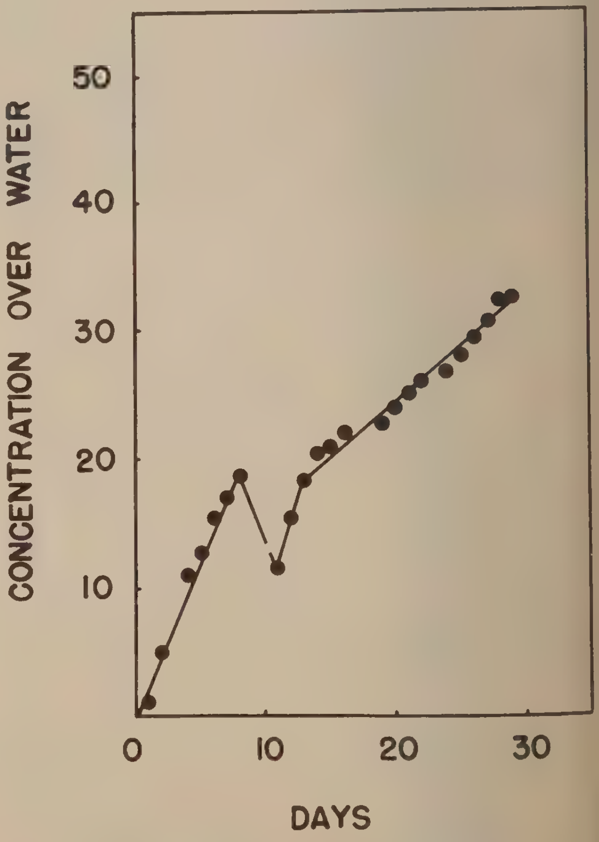

Figure 3. Accumulation of zinc-65 from sea water by the blue crab (Rees, unpublished data).

the radionuclide from the water until molting occurred on the 11th day. The loss of the old exoskeleton and the zinc-65 associated with it, resulted in the loss of 42 per cent of the radioactive zinc accumulated up to that time. In two days of very rapid uptake the level of zinc-65 in the crab returned to virtually the same level that existed just prior to the molt. From this time until the termination of the experiment, accumulation continued at a steady rate, but at a somewhat slower rate than before the molt. Why not the same rate as before the molt? It must be remembered that measurements are being made of the accumulation of zinc-65 by an animal that is morphologically and physiologically different from the animal before the molt. There has been a 23 per cent increase in the weight of the crab and and increase of about 30 per cent in linear dimensions. The tissues of the animal now contain a much higher percentage of water than before the molt, and there are profound physiological changes associated with the formation of new tissues and the hardening of the new exoskeleton. Many factors are at work here, some tending to increase the rate of accumulation and some tending to decrease it. There is every reason to expect that it would not be the same as it was before.

When animals that normally contain high concentrations of zinc are exposed to radioactive zinc, there will be a rapid accumulation of zinc-65 in the tissues. If the zinc-65 subsequently disappears from the environment or if the animals are moved to an area in which zinc-65 is not present, there will be a gradual loss of zinc-65 from the animal. In an experiment designed to measure the loss of zinc-65 by hard shell clams, Mercenaria mercenaria, the animals first were labeled by maintaining them for 20 days in sea water containing zinc-65. At the end of this time the clams were transferred to running sea water in the laboratory and 59 days later to trays immersed in sea water off the laboratory dock. The retention of zinc-65 was followed and is shown in Figure 4. Zinc-65 was lost rapidly during the first 30 days in the laboratory. During the next 29 days the amount lost was drastically reduced. After the clams were placed in sea water off the dock on the 59th day the rate of loss of zinc-65 from them increased again. During the next 30 days they lost about the same percentage of zinc-65 which was contained in them on the 59th day as was lost during the first 30 days of the experiment. Possibly, the increased loss of zinc-65 after being placed in natural sea water off the dock was the result of an improved physiological condition.

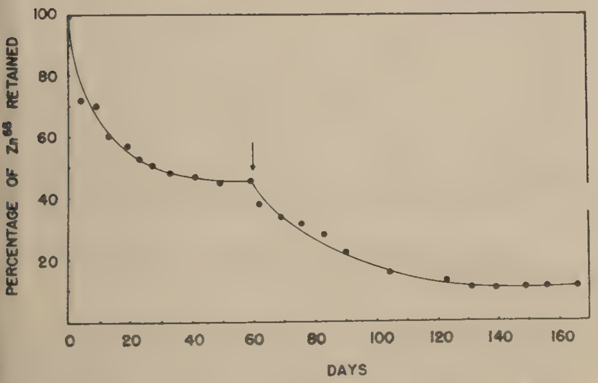

Figure 4. Retention of zinc-65 by clams. Arrow indicates the time at which clams were transferred from the laboratory to the natural environment (Price, unpublished data).

The effect of temperature on the loss of zinc-65 from the blue crab was followed. Zinc-65, made up in "crab saline", was injected directly into the blood of the animals. At winter temperatures in running sea water which varied from 4.5° to 14° centigrade, the crabs retained approximately 50 per cent of the original dose after 104 days (Figure 5). At summer temperatures in running sea water kept at 25° centigrade the crabs still contained 38 per cent of the original dose after 60 days. From these results it can be concluded that zinc-65 in blue crabs may be retained for longer periods of time at low temperature. It also emphasizes the importance of environmental factors on rates of loss.

There is a widespread belief that the retention curve for radioactivity in marine organisms is an exact reverse of the uptake curves. The accumulation of zinc-65 from food by post larval flounders, Paralichthys sp., and its retention when the fish were transferred to non-labeled running sea water were followed (Figure 6). The

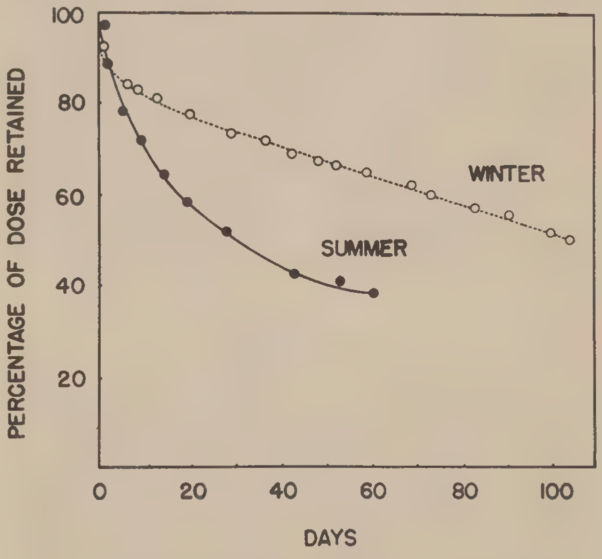

Figure 5. Retention of zinc-65 by blue crabs at summer and winter temperatures (Rees, unpublished data).

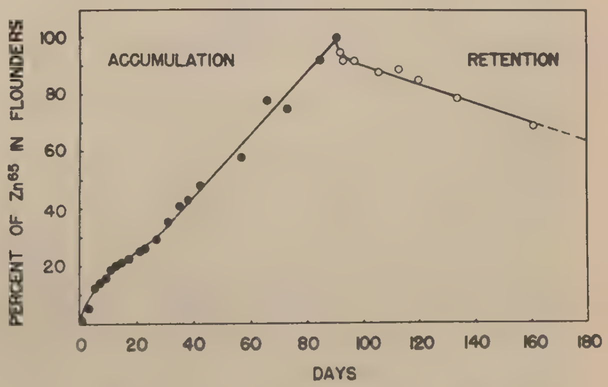

Figure 6. Accumulation and retention of zinc-65 by postlarval flounders. The zinc-65 accumulated after 91 days equals 100 per cent (after Hoss, unpublished data).

difference in the two rates is obvious. Of the zinc-65 accumulated during 91 days the fish were fed, only about 35 per cent was lost after the fish had been in running sea water for 89 days. The line representing the loss of zinc-65 from the flounders was extended from the 160th to the 180th day at the same rate which had occurred from the 91st to the 160th day. It is obvious from this curve and the two previous curves that, regardless of whether the animal is a clam, crab, or fish, the loss of zinc-65 occurs at a slower rate than the rate of accumulation.

The clam received its zinc-65 by direct uptake from the water; the crab from an injection into the blood stream; and the flounder from food. This slower rate of loss compared to accumulation must have been due in part to the high concentration of zinc in these animals at the beginning of the experiment. It would follow that the specific activity in the water immediately after the introduction of zinc-65 would be greater than that which could exist in an animal prior to the attainment of a state of equilibrium. Thus, the zinc-65 was diluted in a large reservoir of stable zinc in the animal and would require the turnover of more zinc to rid the animal of this zinc-65 than was required to obtain it. Therefore, a longer period of time would be required for the loss than for the uptake of zinc-65 under these conditions. This phenomenon is very important in instances of acute pollution since animals will retain zinc-65 for a longer period than the zinc-65 will be maintained at any appreciable level in the water. This will result in observed concentration factors being higher than they would have been if the availability of the zinc-65 had not been reduced.

DISCUSSION

It is possible that zinc-65 may become more important as a pollutant in the aquatic than in the terrestrial environment. The main source of entry of zinc-65 into the terrestrial environment is from fallout with a limited quantity from irrigation water. Of the zinc-65 that falls upon the terrestrial environment, a portion will eventually occur in the aquatic environment. Few or none of the induced radionuclides, including zinc-65, were present in island soil in the Pacific in the vicinity of the nuclear detonations, nor in plants growing in the soil, nor in herbivorous field rats (Rattus exulans) (Lowman et al., 1957). On the other hand, more zinc-65 will fall upon the aquatic environment since more of the earth's surface is covered with water than with land. In addition, water is used for cooling purposes both with land-based reactors and those in submarines and ships. It has been shown that once zinc-65 has entered the aquatic environment, it will rapidly move through the biota and appear in organisms used as food by man.

It appears that zinc-65 is concentrated to higher levels by aquatic organisms than by terrestrial organisms, based on available data. The highest concentration factors that could be found in the literature for terrestrial plants or animals are in the hundreds, while concentration factors for aquatic plants and animals are in the thousands. This may be partially explained by the fact that in addition to the metabolic uptake of zinc-65 by aquatic organisms, considerable amounts are adsorbed on their surfaces. Also, much zinc-65 in soils never reaches the plant since it is adsorbed or chemically bound in the soil.

The amount of zinc-65 varies from organism to organism in all the environments and between organisms in the different environments. The extent to which zinc-65 would be concentrated in many organisms is not known. However, it will be much easier to control the levels of zinc-65 getting to man through food webs in the terrestrial environment than through food webs in the aquatic environment. This is due to man's having more control over the food of domestic animals than over food of aquatic organisms used as food by him.

Zinc-65 is not as important in the oceans immediately following a nuclear explosion or in effluent water at the time of its release from reactors as it is later. This is clearly demonstrated by the observations of Lowman et al. (1957) and of Lowman (1960) who found that zinc-65 accounted for only a small percentage of the radioactivity in marine plants and animals shortly after the detonation of a nuclear device, due to the presence of large quantities of fission products. However, six weeks later zinc-65, together with iron-59 and cobalt-57, 58 and 60, accounted for virtually all the radioactivity in biological samples of marine origin. A similar condition has been observed downriver from the Hanford atomic energy plant by Foster and Junkins (1960). They reported that a few nuclides such as phosphorus-32 and zinc-65 were comparatively low in abundance in the effluent initially, but later contributed most of the radioactivity likely to be found in food products.

SUMMARY

Zinc has been shown to be an almost universal constituent of living matter and is considered essential for the growth and normal development of most microorganisms, plants, and animals. It is now necessary that the role of zinc in the terrestrial, fresh-water, and marine environments be delineated since zinc-65 has been shown to be present in all three. Zinc-65 occurs in these environments as an induced radionuclide, produced at the time of nuclear detonations or in water used as a coolant for nuclear reactors. It has a half-life of 245 days and has been used widely for biological studies. Difficulties encountered in the analytical determination of zinc at levels existing in plants and animals and equal difficulties of freeing water and reagents from contamination with zinc have been deterrents to zinc research.

(1) Some soils naturally contain insufficient total or available zinc to meet the requirements of plant growth. On these soils the use of zinc-containing sprays and fertilizers has become standard agricultural practice.

(2) Direct foliate absorption through the leaves of sprinkler-irrigated crops has been shown to be an important pathway in the uptake of zinc-65.

(3) Zinc-deficiency symptoms in plants have resulted from excessive liming of the soil and on soils containing a high phosphate content.

(4) Plants apparently vary greatly in their zinc requirements and also in their ability to obtain zinc from a given soil.

(5) Zinc-65 taken up by bean plants was found to be present in greatest quantities in the roots.

(6) High concentrations of phosphate prevent zinc from being uniformly distributed throughout the plant. It is not commonly retranslocated from older leaves to younger leaves as the plant grows.

(7) Zinc-65 has been found in all farm prodce sampled from an irrigation project about 30 iles downstream from the Hanford reactors.

(8) The distribution of zinc-65 in a beef nimal from this project was determined. Hair, one, and liver were found to concentrate it to greater extent than the other tissues.

(9) Zinc-65 can exist in the following three hases in the aquatic environment: water, sediment, nd biota. At any given time, factors are in opration in this environment tending to dilute and isperse radioactive materials while simultaneously ther conditions are concentrating the radionuclide.

(10) The quantity of zinc that occurs in fresh ater varies considerably from one location to nother.

(11) Zinc-65 has a marked tendency to be fixd in or on planktonic organisms and suspended silt.

(12) Zinc-65 is readily transferred through he food web and occurs in relatively large conentrations in most all Columbia River organisms ampled.

(13) Many radionuclides in fish in the olumbia River decreased greatly during the winter ut concentrations of zinc-65 remained relatively onstant throughout the year.

(14) Zinc-65 occurred in all tissues of fish xamined, with concentrations in the eye three or ore times greater than in any other tissue.

(15) In the last few years considerable mphasis has been placed on the advantages of the ea as a disposal site for radioactive wastes.

(16) Zinc-65 is among those radionuclides hich could be more dangerous to man when occuring in the oceans.

(17) Analyses of marine plants and animals ave shown that the concentration of zinc in them xceeds the concentration in sea water by 1,000 imes or more.

(18) The amounts of zinc occurring in natural ea water are far in excess of the needs of a culure of phytoplankton.

(19) Above the first trophic level the rate f accumulation of zinc-65 may be influenced by hether the uptake of the nuclide is occurring rom only the water or the food of the animal.

(20) *Artemia* obtaining zinc-65 from food ontained more zinc-65 throughout an entire experient than other *Artemia* obtaining zinc-65 from ater.

(21) The physiological condition of the nimal and the temperature of the water are among he factors influencing the rate of loss of zinc-5 from marine animals.

(22) Loss of zinc-65 from marine animals laced in sea water containing no zinc-65 occurs t a slower rate than the rate of accumulation.

(23) This phenomenon is very important in nstances of acute pollution since animals will etain zinc-65 for a longer period than the zinc-5 will be maintained at any appreciable level n the water. This will result in observed conentration factors being higher than they would ave been if the availability of the zinc-65 had een maintained in the water.

ACKNOWLEDGMENTS

The author thanks Donald E. Hoss, Thomas J. Price, and George H. Rees of the Radiobiological Program, Beaufort, N. C., a cooperative project of the U. S. Bureau of Commercial Fisheries and the U. S. Atomic Energy Commission, for permission to use their unpublished data.

This paper was prepared under a cooperative agreement between the U.S. Atomic Energy Commission and the U.S. Bureau of Commercial Fisheries.

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SALMON SEROLOGY

by George J. Ridgway and Fred M. Utter

mong the methods being applied to the problem letermining the amount of intermingling of Asian l American stocks of salmon in high seas areas various serological or immunochemical methods. ese methods are used to detect characteristic igenic differences which may occur in different quencies in genetically isolated populations.

he research which we have conducted includes earch on cellular antigens, serum antigens and dies on the use of antigenic and histological changes indicators of the onset of sexual maturation.

RESEARCH ON CELLULAR ANTIGENS

ur studies on the antigens of red blood cells of l, chum, and pink salmon were continued and panded in the 1961 season. More intensive npling in the Bristol Bay area and the use of a ich larger number of reagents allowed us to make eral important demonstrations of antigenic varia- ns between areas. Samples were also taken and ted aboard the chartered vessel MV *Bertha Ann*, owing us to demonstrate the feasibility of con- cting many of our tests and procedures on the high s when a vessel with sufficient room is available. addition to Western Alaska areas, the Fraser, agit and Columbia River fisheries were sampled d tested extensively.

The sources of the agglutinins used in these studies re heterimmune sera, normal sera, isoimmune a and phytoagglutinins from plant extracts. nong the immune antisera tested, eight goat anti- mon tissue sera, four carp anti-salmon red blood l sera, seventeen chicken anti-salmon red blood ll sera, four carp anti-red cell sera, and five rainbow ut isoimmune sera demonstrated at least some gree of intra- or inter-specific differentiation. Ten bbit anti-salmon tissue sera and a number of other a of diverse origin did not detect differences.

The phytoagglutinins used included over thirty- e extracts, many of which reacted strongly. tensive testing under controlled conditions tended place in doubt interpretations of observable dif- ences using several of the extracts—principally tracts of baby lima bean—as the results were often t repeatable and appeared to vary with age of ll samples. Several extracts appear to show antigenic variation of a consistent nature, including *Wistaria floribunda* bark, red kidney bean, and *Cytisus scoparius* bark. *Cytisus* appears the most promising at present and has been tested against cells from various areas with good demonstration of variability between populations of red salmon (see Table 10).

TABLE 10. The relative numbers of red salmon from several areas giving different reactions with *Cytisus scoparius* bark extract.

River	Agglutination score			Total number tested	Mean score
	0	0.5–2	2–5+		
Branch River	2	34	11	47	1.86
Kenai River	8	12	0	20	0.675
Karluk River	0	14	11	25	2.60
Fraser River	24	7	1	32	0.453
Columbia River	5	3	2	10	1.05

Normal sera from many species of land animals and fishes have been extensively tested. One hundred and ten different land animal sera were provided and tested by Dr. C. Stormont. These include sera from a wide variety of species obtained at the San Diego Zoo and numerous sera from domestic animals. In addition, twenty-five normal horse sera, sixteen normal rabbit sera, English sole sera, crayfish sera, and others have been extensively tested. In general, these tend to demonstrate strong inter-specific antigenic differentiation, but intraspecies differences to a lesser extent.

Isoimmune antisera testing has been limited to sera from rainbow trout. Five have shown clear intra-specific differentiation in red salmon and marked differences between populations even within Bristol Bay (Table 11). Several have also demonstrated intraspecific antigenic variability in pink and chum salmon. We consider this the most important advance made so far in our work, since isoimmune sera are known to detect far greater numbers and finer antigenic differences than other sources of blood typing reagents. In addition, these sera show the most striking and consistent differences of any of the reagents we have so far tested. Some of the properties of these sera and the methods used in their preparation were described in a paper presented to the New York Academy of Sciences at a symposium on "Blood Groups in Infra-human Species".

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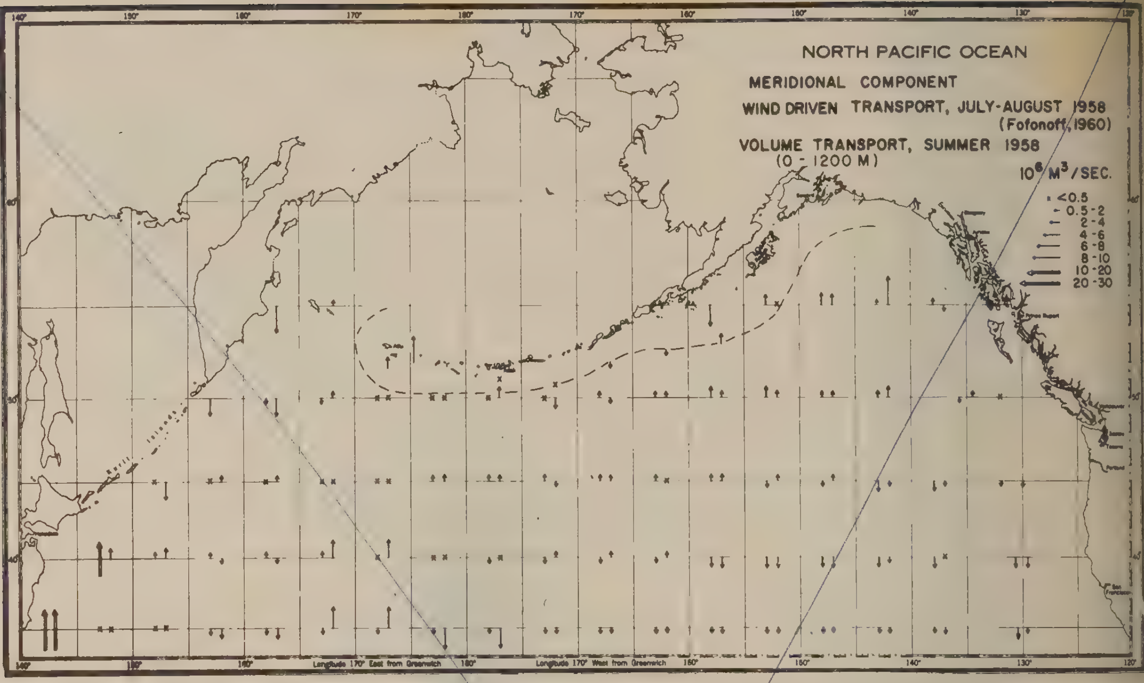
NORTH PACIFIC OCEAN
MERIDIONAL COMPONENT
WIND DRIVEN TRANSPORT, JULY-AUGUST 1958
(Fofonoff, 1960)
VOLUME TRANSPORT, SUMMER 1958
(0 - 1200 M)
10⁶M³/SEC.
<0.5
0.5-2
2-4
4-6
6-8
8-10
10-20
20-30
Longitude 170° East from Greenwich
Longitude 170° West from Greenwich

FIGURE 23. Comparison of meridional components of geostrophic mass transport computed from wind stress (left arrow in each set) and volume transport computed from hydrographic data from 0 to 1200 meters (right arrow in each set) during Summer 1958. (Dashed line shows approximate extent of Alaska Boundary Current.)

We are presently evaluating a differential refractometer and will also test an inductive salinometer, both of which appear to fulfill our requirements at this time. The differential refractometer provides precision and accuracy comparable with conductivity salinometers presently in use. The sample and reference cells have small volumes, and little maintenance is required for the instrument. The inductive salinometer also is portable, does not require a temperature-controlled bath, and has accuracy of approximately 0.003 parts per thousand.

BIOLOGICAL OCEANOGRAPHY

All plankton data collected prior to 1961 have been placed on IBM cards to permit qualitative and quantitative comparisons between individual years, and to investigate relationships between the plankton captured by net and the contents of red salmon stomachs.

In 1960 and again in 1961, studies on the vertical distribution of plankton have been made at three locations in the Subarctic Region. Results show that maximum concentrations of plankton occur between 30 to 50 meters depth at night and at depths of 150 meters or greater during the day. This place considerable doubt on the generally accepted theor that salmons come to the surface in the evening o morning to feed. Night light studies have show that squid are abundant at the surface in this Region but we do not know whether or not they are attracted to the surface by the light. Comparison of the plankton and the stomach content of salmo caught at these locations, and investigations int relationships between the plankton and the thermocline are being carried out.

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TABLE 11. The relative numbers of red salmon from six Bristol Bay streams reacting with two rainbow trout isoimmune sera.

Serum	Area	Number tested	Number reacting	Percent reacting
96	Kvichak	72	42	58.3
	Branch River	25	8	31.2
	Wood River	10	2	20.0
	Egegik	16	4	25.0
	Ugashik	12	3	25.0
	Naknek	12	5	41.7
		$X^2=12.82$*		
101	Kvichak	72	46	63.9
	Branch River	25	17	68.0
	Wood River	10	5	50.0
	Egegik	16	8	50.0
	Ugashik	12	12	100.0
	Naknek	12	11	91.7
		$X^2=13.07$*		

* Significant at the 95 percent level.

The application of these sera directly to the Protocol problem will undoubtedly require testing blood from freshly caught salmon in Asian areas and in areas of suspected intermingling of Asian and American stocks. (This is due to the fact that salmon blood cells are not preserved intact for any appreciable time by techniques presently available.) The relative availability of fresh blood from salmon caught by North American shore based fisheries allows us to apply these sera now to problems important to the understanding and management of these fisheries.

RESEARCH ON SERUM ANTIGENS

The demonstration of characteristics designated antigens I and II which were present in 95 to 98 percent of red salmon blood samples tested from American areas and absent from 85 to 90 percent of red salmon blood samples tested from Asian areas has been reported previously. Further practical expansion of these results has met with difficulties of two sorts. The first involves the difficulty in producing sufficient antisera of the same specificity to test large numbers of samples. The second difficulty involves the resolution of apparent discrepancies between the results obtained with this method and those obtained with other methods of determining the continental origin of red salmon taken in the high seas.

In our report of last year we stated: " We feel it is essential to make a more thorough study of the nature of the difference being detected, and the effect of such variables as may be introduced by sampling and preservation methods, before further application of this method is possible. It will also be essential to perfect methods for the consistent production of large quantities of potent and specific antisera." In our attempts to solve the problems of antiserum production we have immunized 50 rabbits and collected and tested serum from 250 bleedings. Of these sera 122 show definite individual differences. We are conducting extensive tests by several methods to compare the specificities of these sera with those detecting previously studied differences. One of the methods being used for these comparisons is immunoelectrophoresis. A separate manuscript describing some of our results with immunoelectrophoresis will be submitted. One most significant finding so far is that the interaction of the hemoglobin in hemolysed blood under certain conditions can interfere with the tests for important serum components. This is especially true of three serum characters discovered after antigens I and II. These have been designated H, H′ and C. We have been and are studying this problem intensively by a variety of methods. For two years now personnel of the serology investigations have accompanied charter vessels to collect separated serum samples and study the feasibility of conducting some of our tests on board these vessels. All of our work indicates that facilities must be available on research vessels to operate centrifuges, separate the serum from fresh unhemolysed blood, and conduct agglutination tests directly on board before we will be able to accurately apply the reagents we have available to the study of high seas populations.

Certain plant extracts have been found to precipitate soluble components of various fish sera in a manner analogous to immune sera. Among these, four have demonstrated individual variation in various salmonid species. The specificities of these reagents when compared by double diffusion have been found to be independent of one another as well as independent of the specificities of immune reagents tested. Although extensive tests with these reagents have not been made, further study on properly preserved samples may show that the serum components detected by these plant extracts are useful racial markers.

RESEARCH ON MATURATION IN SALMON

We have previously reported the discovery of an antigenic fraction which apparently occurs in the serum of only maturing or mature female salmon. In the past year we have tested the heart blood from 2,955 chum salmon being processed by the morphology laboratory. Of these fish 619 were taken by the U.S. chartered research vessel MV *Pioneer* in 1959 and 686 taken by the same vessel in 1960; 1,510 were taken by the U. S. chartered research vessel MV *Paragon* in 1960 and 138 were taken by Japanese vessels in 1959. Of these, 1,608 were females and 815 gave positive tests for the female maturity (Sm) antigen.

Table 12. The correlation of gonad weight with presence of Sm antigen in the sera of female chum salmon.

Gonad weight (gr.)	Total females tested	Number positive	Percent positive
<8	165	8	4.9
8–9	121	22	18.9
10–11	71	18	25.4
12–13	90	34	37.8
14–15	21	7	33.3
16–17	14	8	57.1
18–19	14	10	71.1
≥20	253	250	98.8

Table 12 shows the correlation between gonad weight and the possession of Sm antigen by female chum salmon. If the possession of the Sm antigen is a good indicator of maturation one can be quite certain that a female chum salmon with gonads weighing 20 or more grams is maturing. For those with gonads weighing less than 20 grams there is considerable uncertainty which possibly can be resolved by tests for the Sm antigen.

In order to have additional criteria for maturity in salmon, we collected and fixed gonad samples aboard the MV *Paragon* in 1960 for histological studies. These studies were conducted by Dr. E. M. Wood and a manuscript describing the results is being submitted. They may be summarized as follows: Maturing salmon gonads pass through a series of structurally well defined stages. Active spermatogenesis and the onset of sexual maturation appears to begin when the first spermatogonia are formed. Active oogenesis apparently starts with the formation of secondary oocytes and the appearance of the two layered zona radiata.

SUMMARY

1. Research on serology has been continued along three main lines in studies on red blood cell antigens, serum antigens and on maturity.

2. In the studies on red blood cell antigens a great many additional reagents have been studied. These include heterimmune sera produced in rabbits, chickens, goats and carp; normal sera of many domestic and wild mammals and fish; isoimmune sera produced in rainbow trout; and phytoagglutinins from plant extracts.

3. Clear cut qualitative intraspecific variations in the blood cell antigens of red, pink and chum salmon were demonstrated with five rainbow trout isoimmune sera. Significant differences among Bristol Bay populations of red salmon were demonstrated with two of these sera.

4. In studies of serum antigens 50 rabbits were immunized and serum from 250 bleedings collected and studied. Of these 122 gave evidence of individual differences in red salmon. Evidence was obtained which indicated that the presence of hemoglobin in lysed blood preparation influences the tests for some variable serum components.

5. The method of immunoelectrophoresis was adapted to the study of serum antigens of salmon.

6. Certain plant extracts were found to specifically precipitate with salmon sera. Some detect inter-specific and intra-specific differences.

7. In order to assist in determining the maturity of salmon collected on the high seas, the heart bloods of 2,955 chum salmon have been tested for the presence of an antigen which occurs in the blood of maturing females.

8. A study of the histology of salmon gonads has been made to assist in establishing criteria for maturity.

MORPHOLOGICAL CLASSIFICATION OF 1960 RED SALMON

by B. J. Landrum and T. Dark

Since 1955, the morphological differences between the principal races of red salmon were examined using multivariate analytical techniques. On the basis of the results from tagging, parasite studies and distance function analysis of morphological characters, it was concluded that the maturing red salmon in the

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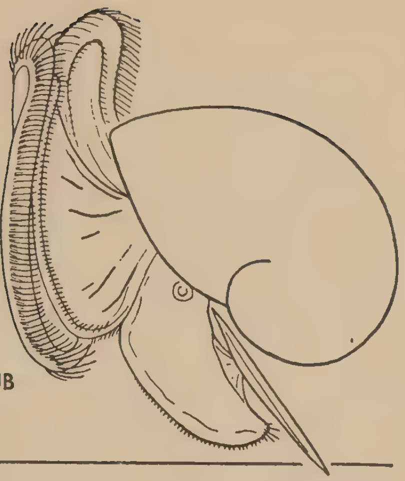
THE VELIGER



A Quarterly published by
NORTHERN CALIFORNIA MALACOZOOLOGICAL CLUB
Berkeley, California

VOLUME 6 OCTOBER 1, 1963 NUMBER 2

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Note: The various taxa above species are indicated by the use of different type styles as shown by the following examples:

ORDER, Suborder, **DIVISION, Subdivision,** SECTION,
SUPERFAMILY, FAMILY, Subfamily, ***Genus***, ***(Subgenus)***.
New Taxa

Abnormal Dextral Hyperstrophy of Post-Larval *Heliacus*

(Gastropoda: Architeconicidae)

BY

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AND

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(Plates 13 and 14)

In 1868, Lagoda described and figured (see Plate 13, fig. 2) a "sinistral," scalariform gastropod shell, naming it (on the plate only) "*Torinia variegata,* Lamarck, var. *sinistrorsa.*" In this paper we present proof that a similar abnormally coiled "*Torinia*" [=*Heliacus*] (Plate 13, fig. 4) is dextral, and that Lagoda's shell was also dextral.

As the terms are used in this paper, dextrality and sinistrality are not defined with reference to the coiling of the mantle-shell and contained viscera — albeit the apertures of most dextral gastropod shells are "right-handed" and of most sinistral gastropod shells "left-handed." Fundamentally, one is anatomically the mirror image of the other. In dextral forms the primitively paired organs associated with the mantle cavity (ctenidia, osphradia, hypobranchial glands, auricles and kidneys) are reduced or absent (except in some primitive archaeogastropods) on the post-torsional right side, and the anus is displaced to the right. In sinistral forms these paired organs are reduced or absent on the left side, and the anus is displaced to the left. The spires of most dextral gastropod shells project to the post-torsional right side, and the spires of most sinistral shells project to the left (the condition termed orthostrophy) — although an elongate spire may be twisted upwards and posteriad during locomotion. However, some larval and a few post-larval gastropods are dextral but have "left-handed" apertures; their "spires" project to the left (hyperstrophy). In effect, the true spire has become a false umbilicus and the true umbilical area a false spire. Thus, a dextral gastropod shell can superficially appear sinistral (and vice versa) if it is hyperstrophic. For diagrams and further discussion of dextrality, sinistrality, orthostrophy, and hyperstrophy, see Knight (1952, pp. 7 to 9, figure 2).

The protoconchs (≈ larval shells) of some gastropods with orthostrophic teleoconchs (≈ post-larval shells) are hyperstrophic. Such protoconchs are possessed by many opisthobranchs, a few primitive pulmonates, and two families (with living representatives) still classified in the Subclass Prosobranchiata (Streptoneura): Mathildidae and Architectonicidae. [For a study of the hyperstrophic larval shells of the Architectonicidae, see Robertson (in preparation, A)]. All gastropods with hyperstrophic proto-

Explanation of Plate 13

Figure 1: *Heliacus bicanaliculatus* (Valenciennes). Normal shell, with orthostrophic teleoconch. South side Bahía San Luis Gonzaga, Baja California Norte, México (West). Intertidal; associated with *Zoanthus danae* (Le Conte) on sides of rocks. Collected by Dr. Donald R. Shasky, May 28, 1961. A. N. S. P. no. 276232. x 5.

Figure 2: *H. bicanaliculatus.* Abnormal shell, with hyperstrophic teleoconch. "Californie." "*Torinia variegata,* Lamarck, var. *sinistrorsa*" Lagoda (from Lagoda, 1868). x 5.

Figure 3: *Heliacus cylindricus* (Gmelin). Normal shell, with orthostrophic teleoconch (surface corroded). Tea Table Key, Florida Keys. Collected by Mr. Thomas L. McGinty. A. N. S. P. no. 195956. x 6. See also Plate 14, figs. 1 and 3.

Figure 4: *H. cylindricus.* Abnormal shell, with hyperstrophic teleoconch. Tea Table Key, Florida Keys. Collected by Mr. Frank Lyman, 1938. U. S. N. M. no. 597759. x 6. See also Plate 14, figs. 2 and 4.

hs normally are dextral, and the change from hyper-
phic to orthostrophic coiling involves only minor re-
tioning of the mantle.

extrality or sinistrality is determined very early in
embryologic development of every living gastropod,
, once determined, is never reversed; either dextrality
inistrality is retained thereafter through life. A change
n sinistral to dextral (or dextral to sinistral) coiling
in larval life is altogether impossible.

here is no *a priori* reason to exclude the possibility
, abnormally, architectonicid shells may occasionally
inistral. However, both the protoconch and the teleo-
ch would have to be sinistral. This profound aberra-
might or might not affect the normal larval hyper-
phy and post-larval orthostrophy.

far less profound aberration, not involving sinist-
y, would be the abnormal retention of the normal
erstrophic larval coiling by a post-larval, benthic
itectonicid. Such an abnormal shell superficially
ld appear sinistral if the "spire" were oriented up-
ds. An architectonicid showing precisely this kind of
rration is illustrated here (Plate 13, fig. 4), together
a normally coiled shell of the same species (Plate
fig. 3) from the same locality (Tea Table Key, Florida
s). This abnormally coiled specimen of *Heliacus*
ndricus (Gmelin, 1791), United States National Mu-
n (U. S. N. M.) no. 597759, can be proved to be
tral and hyperstrophic by using two kinds of evidence:
the coiling of the operculum, and (2) the external
pture of the shell and the form and coloration of the
rture.

ELSENEER (1893) has shown how spiral opercula can
sed to distinguish orthostrophic sinistrality from dex-
hyperstrophy: viewed externally, spiral opercula of
tral gastropods are coiled counterclockwise, and of
stral gastropods clockwise. The *Heliacus* operculum is
onical, spiral, and lamellar structure (Plate 13, figs.
). As can be seen from Plate 14, figures 1 and 2, the
ing of the apices of the opercula in the normal and in
abnormal specimens is counterclockwise.

here are thirteen normal specimens of *Heliacus cylin-*
us from Tea Table Key (Florida Keys) in the collec-
at the Academy of Natural Sciences of Philadelphia
N. S. P. nos. 195956, 221378, and 264095). The ex-
nal sculpture of these shells consists of broad spiral
ds separated by sulci. The spiral cords are irregularly
nkled by axial growth lines. In the umbilicus, the
ds and sulci are absent or obscure. Not counting these,
re are ten sulci on the last whorl of each of the thirteen
lls. There are eleven cords of various widths separated
sulci (including the cord at the periphery of the umbil-
and the irregular cord below the suture). Along the
center of some of the sulci there are raised lirae. With the sulci counted clockwise from the suture (Plate 14, fig. 3), lirae most frequently are present in sulci 3 and 5 (on some specimens the lirae are wide enough to resemble narrow cords). Lirae may also be present in sulci 4, 6, and 7, and rarely in sulci 1 and 2. On normal shells, lirae invariably are absent from sulci 8, 9, and 10 (i. e., those on the umbilical half of the base).

Using conchological evidence, it can be shown in three ways that the apertures of the normally and abnormally coiled shells (Plate 14, figs. 3, 4) are both oriented in the same way (i. e., that fig. 4 shows a dextral hyperstrophic shell). On the exterior of the abnormal shell, lirae are present in sulci 2, 3, 4, 5, and 6. If the sulci are counted counterclockwise from the (false) suture (FS), these are sulci v, vi, vii, viii, and ix. Unless the shell is hyperstrophic, the presence of lirae in sulci "8" and "9" is discordant with the normal external sculpture.

The form of the aperture is the second conchological indication that the abnormal shell is properly oriented. The anterior siphonal channel (ASC) is in almost the same position in both apertures. Curiously, in the abnormal shell this channel is opposite the cord between sulci 9 and 10, while on all normal shells it is opposite the cord between sulcus 10 and the umbilicus.

The coloration of the aperture is the third indication of correct orientation. Within, the aperture of the abnormal shell is yellowish brown except the upper left quadrant, the parietal area (PA), where it is white tinged with very pale amber. This area corresponds to the parietal callus of normal shells, which is thinner (affixed to the parietal wall), semitransparent, and white or very pale amber. The parietal area is in the same position in both apertures.

In 1867, more than two decades before the reality of hyperstrophy was conclusively proved, Lagoda not unnaturally assumed that his abnormal "*Torinia variegata*" was sinistral. In a paper in which the concept of hyperstrophy was questioned, Fischer & Bouvier (1892, p. 125) included "*Torinia variegata*" in a list of the then known teratologically "sinistral" gastropods. Pelseneer (1893) wrote an elegant paper in rebuttal, one of his series of papers proving the reality of hyperstrophy.

Without discussion, Charles Bayer (1948, p. 28) has stated that "*Torinia variegata*, Lamarck, var. *sinistrorsa* Lagoda" is a "laeotropic [i. e., sinistral] scalarid" [i. e., epitoniid], not a "*Torinia*." In our opinion this statement is incorrect and there is no reason whatever to question Lagoda's generic identification. Lagoda's shell was white variegated with brown, had the granulated spiral cords of *Heliacus*, and lacked the axial costae possessed by most epitoniids.

Lagoda stated that his shell was brought to him from "Californie" by a friend. The genus *Heliacus* does not occur on the California coast proper. However, the name *Torinia variegata* (Lamarck, 1816) used to be misapplied to *Heliacus bicanaliculatus* (Valenciennes, 1832), which does occur in the Gulf of California. Four lots of this species in the Academy's old collection are labeled *"variegata,"* and one is labeled merely "California." True *Heliacus variegatus* (Lamarck, 1816) is an Indo-West Pacific species, whereas *H. bicanaliculatus* ranges from Bahía San Luis Gonzaga (Baja California Norte) south to Acapulco (Guerrero), México (Keen, 1958, p. 293), and (near the northern end of its range) is a symbiont with the colonial (zoanthiniarian) sea anemone *Zoanthus danae* (Le Conte) (Robertson, in preparation, B).

A normal shell of *Heliacus bicanaliculatus* is illustrated here (Plate 13, fig. 1) at the same magnification (x 5) as that of Lagoda's shell (Plate 13, fig. 2). Despite the different size and greatly different shape and appearance, we believe that Lagoda's shell was probably a young, dextral, hyperstrophic *H. bicanaliculatus.* The difference in size is noteworthy. Lagoda's shell had five whorls. Full-grown *H. bicanaliculatus* has no more than five and three quarters whorls. We suggest that the abnormal coiling may have increased the relative number of whorls of the young shell.

Normal shells of *Heliacus bicanaliculatus* have ten granulated, spiral cords of various widths on the last whorl (excluding those in the umbilicus). Above the periphery there are four of these cords; below and on the base there are six. The shells are variously patterned with brown. Twenty-two of the forty normal shells in the Academy's collection have the brown paler below the periphery than above; two lack brown coloration below the periphery altogether; sixteen have as much brown below as above, and in none is the brown pale or lacking above the periphery. Lagoda's shell had four spiral cords above the periphery and six (?) below, and nearly all the brown markings are above the periphery (orientation of Plate 13, fig. 2). Lagoda's shell contained neither the dried animal nor the operculum. Nevertheless, this conchological evidence is enough to show that Lagoda's abnormal shell was closely comparable to the dextral hyperstrophic specimen of *H. cylindricus* (Plate 13, figure 4).

Both abnormal shells are scalariform and have partially disjunct whorls. Their apertures are slightly more elongate than those of normal shells. Normal, full-grown shells of *Heliacus bicanaliculatus* and *H. cylindricus* have spire angles of 70° to 98° (average 83°) and 66° to 83° (average 73°) respectively. The angle of the false spire of the abnormal specimen of the former species is approximately 40°; that of the latter is 30°.

Lagoda wrote his article in "Saint-Pétersbourg" (now Leningrad) in 1867. It was published in Paris the following year. Lagoda's dextral hyperstrophic *Heliacus* was in his private collection. Searches in the major shell collections in Leningrad and Paris have failed to locate his specimen (see Acknowledgments).

Whether post-larval hyperstrophy was caused twice by an injury to the mantle of a larva cannot, unfortunately, now be determined. Lagoda did not adequately describe and illustrate the apex of his shell, and the spire of the dextral hyperstrophic *Heliacus cylindricus* is decollated (three and one half whorls remain).

The normal coiling of the thecosomatous pteropod *Spiratella* [incorrectly *"Limacina"*] is directly comparable to the abnormal coiling of the two *Heliacus* specimens in that all are dextral and hyperstrophic. *Spiratella* can be considered a neotenous opisthobranch larva, remaining in the plankton throughout life. The shell remains hyperstrophic throughout life. The larvae of *Heliacus* likewise have dextral hyperstrophic shells and are pelagic. However, they soon settle to the bottom and are thereafter benthic. Although having the larval coiling, the two abnormal *Heliacus* specimens undoubtedly were benthic; both have fairly thick, heavy shells, one 13 mm long, the other 15 mm long. The largest *Spiratella, S. helicoides* (Jeffreys, 1877), does attain a shell diameter of 12.5 mm (Tesch, 1946, p. 9), but has a much thinner shell and long parapodial "wings" used for swimming.

A few other gastropods normally are dextral and hyperstrophic throughout life. A good example is *Lanistes,* a benthic, fresh-water prosobranch. To our knowledge, ours

Explanation of Plate 14

Figures 1 and 2: *Heliacus cylindricus* (Gmelin). Views showing the counterclockwise (dextral) coiling of the multispiral operculum (*in situ* in the aperture) of the normal (fig. 1) and abnormal (fig. 2) shells. Both x 14.
Figures 3 and 4: *H. cylindricus.* Diagrams showing the sculpture on the exterior of the outer lip, and the form and coloration of the aperture of the normal (fig. 3) and abnormal (fig.4) shells. The parietal area (PA), anterior siphonal channel (ASC), suture (S), false suture (FS) and sulci (numbered 1 to 10 and i to x) are shown. In fig. 3 there are lirae in sulci 3 to 7; in fig. 4, in sulci 2 to 6 (the lirae in sulci 5 and 6 are wide). Both x 10.
Note: All the shells illustrated on both plates are dextral and all are conventionally oriented (with the aperture to the right of the axis of coiling).

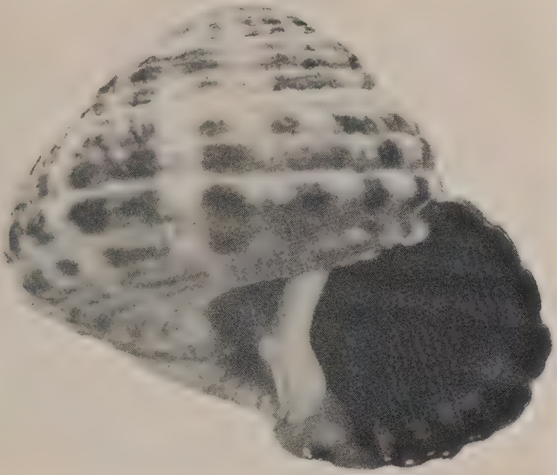

Figure 1

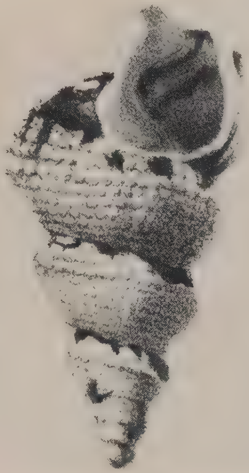

Figure 2

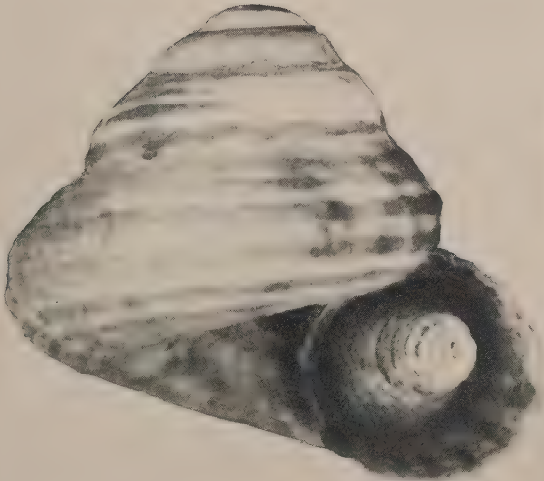

Figure 3

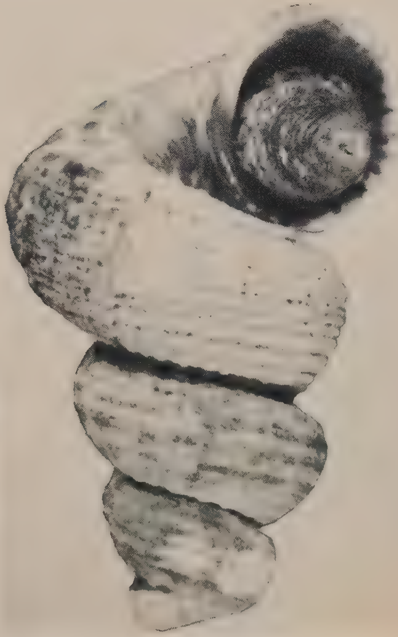

Figure 4

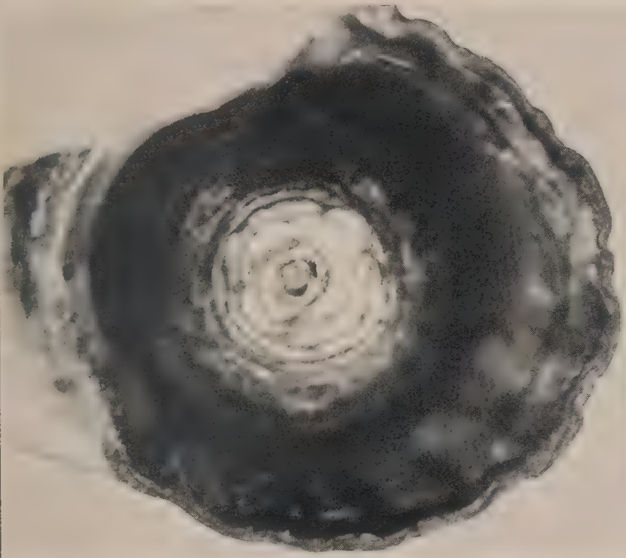

Figure 1

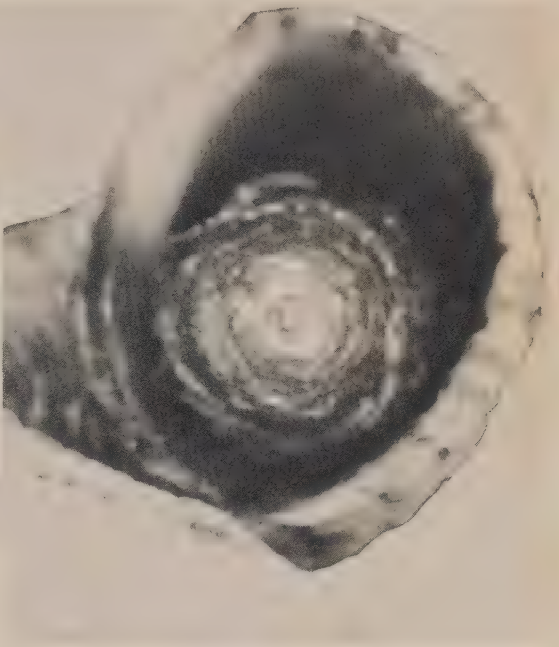

Figure 2

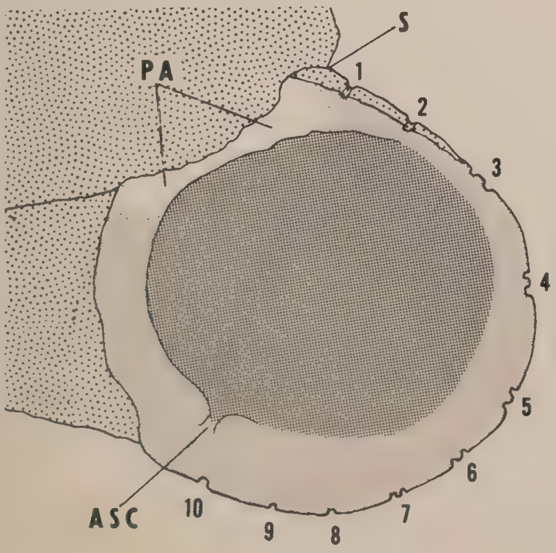
S
PA
1
2
3
4
5
6
7
8
9
10
ASC

Figure 3

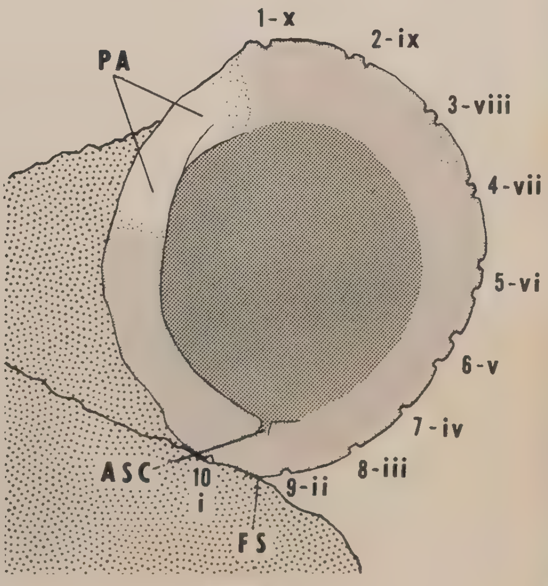
1-x
2-ix
PA
3-viii
4-vii
5-vi
6-v
7-iv
8-iii
9-ii
ASC
10
i
FS

Figure 4

he first report of abnormal, post-larval dextral hyper-ophy in gastropods normally having hyperstrophic toconchs. [The "sinistral," semi-terrestrial ellobiid *uneria* may be a benthic example of a dextral gastro-d with the hyperstrophic coiling of the protoconch ained normally by the teleoconch. This possibility pears never to have been investigated.] Our discovery s bearing on the relative adaptive values of orthostro-y and hyperstrophy.

Abnormal hyperstrophy must have had minor or no verse effects on the two post-larval, benthic *Heliacus* ecimens. Despite their retained larval coiling, these mals survived their abnormal (incomplete) metamor-osis and grew shells 13 mm and 15 mm long. Theoret-lly, hyperstrophy should impede benthic locomotion d possibly also the removal of wastes from the anus and ntle cavity. The usual orientation of the foot is versed relative to the "spire" of the shell, as is also e position of the anus. During locomotion, the shell-ntle and contained viscera would have to be twisted ore than 90° relative to the head-foot mass because herwise the false spire of the shell would be pushed ead of the foot. A hyperstrophic *Heliacus,* living in dentary association with zoanthiniarian sea anemones, ould find such locomotory and associated problems nimized. More active benthic gastropods might not vive abnormal hyperstrophy.

SUMMARY

All normal architectonicids are dextral and have hyper-ophic protoconchs and orthostrophic teleoconchs. *"To-ia variegata,* LAMARCK, var. *sinistrorsa,"* described by GODA (1868), is probably a young, abnormally coiled *liacus bicanaliculatus* (VALENCIENNES). This species es on the West coast of México in association with *anthus danae* (LE CONTE), a colonial sea anemone oanthiniaria). LAGODA's shell is directly comparable th a full-grown, dextral hyperstrophic specimen of *eliacus cylindricus* (GMELIN) from the Florida Keys. he counterclockwise coiling of the multispiral opercu-m, the shape and external sculpture of the shell, and e form and coloration of the aperture prove that the ter is dextral. Both shells were dextral throughout life, d the normal hyperstrophic coiling of the protoconch was retained abnormally by the teleoconch. Hitherto, such an abnormality appears not to have been reported.

ACKNOWLEDGMENTS

We are indebted to Dr. O. A. Scarlato (Zoological Institute, Academy of Sciences of the U. S. S. R., Leningrad), Dr. P.-H. Fischer (École des Mines, Paris; present editor of Journal de Conchyliologie), and to Mr. J.-M. Gaillard (Laboratoire de Malacologie, Muséum National d'Histoire Naturelle, Paris) for having searched for LAGODA's abnormal *Heliacus.* Upon request, Dr. Donald R. Shasky (Redlands, California) kindly obtained *Heliacus bicanaliculatus* with its host.

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OVERVIEW OF GOVERNMENT-INDUSTRY OCEANOGRAPHIC INSTRUMENTATION SYMPOSIUM

Julius Rockwell, Jr.
Bureau of Commercial Fisheries

My qualification to serve oceanographic instrumentation came about because my mother science was zoology at the University of Michigan and my father science was electrical engineering in the Navy. Since these two have never been properly married I am called an interdisciplinarian.

To understand the interdisciplinary nature of the problems which led to the Government-Industry Oceanographic Instrumentation Symposium, it is necessary to understand the background. The United States is embarking on a long-range National Oceanographic Program similar to our Space Program and other large programs of research and exploration. As a Nation we are considerably behind in oceanographic work. To facilitate a more rapid development in this science, the Committee on Oceanography of the National Academy of Sciences had developed a 10-year minimum plan, described in Oceanography - 1960 to 1970 and available from the National Academy. The plan is being implemented more or less on schedule. Ships are being built to do the necessary survey and research work. Educational facilities are being strengthened, and activities are being accelerated with the support of Federal agencies and individual institutions to provide the necessary manpower. Many agencies offer support to those interested in oceanographic studies. In progress are various legislative actions which will augment this program.

The most critical need is for new and as yet undeveloped instruments to do this work. We can train personnel in universities, and many persons, who previously worked in oceanography, are returning to it. We can build vessels, and the vessel program is well on its way. The National Science Foundation is financing many colleges to increase plant capacity in this field. But with instrumentation it is a different story; here is a bottleneck.

Government wants Industry to share in the development of new instruments. Industry wants to help the national program and many are contacting government agencies to find how they can best serve.

Finding the right group or laboratory to contact is difficult because of the great diversity and location of the agencies which are working in the oceanographic effort. Twenty-two Government bureaus and agencies have a direct interest in oceanography:

Department of Defense.

Navy
- Bureau of Naval Weapons.
- Bureau of Ships.
- Navy Hydrographic Office.
- Navy Weather Service.
- Office of Naval Research.

Army
- Beach Erosion Board.
- Corps of Engineers.

Department of the Interior.

Bureau of Commercial Fisheries.
Bureau of Mines.
Bureau of Sport Fisheries and Wildlife.
Geological Survey.

Department of Commerce.

Coast and Geodetic Survey.
Maritime Administration.
Weather Bureau.

Department of Health, Education, and Welfare.

Office of Education.
Public Health Service.

Department of the Treasury.

Coast Guard.

Department of State.

Special Assistant to the Secretary of State

for Fisheries and Wildlife.

Other.

Atomic Energy Commission.
National Academy of Sciences.
National Science Foundation.
Smithsonian Institution.

Groups of men from individual companies have been visiting each of these agencies to explain their capabilities and to find out how they can serve. Key bureau personnel, on the other hand, have been listening to them and trying to give guidance. Men who can participate in this sort of conversation are scarce and are much needed elsewhere. This procedure is generally time consuming and has not been efficient from either side of the table.

The President's Federal Council for Science and Technology, of which Dr. Wiesner is Chairman, established the Interagency Committee on Oceanography to formulate and to deal with this and other general aspects of the National Oceanographic Program. The Interagency Committee on Oceanography (ICO) in turn, established its Panel on Facilities, Equipment, and Instrumentation chaired by Donald L. McKernan, Director, Bureau of Commercial Fisheries, to solve this and other problems pertaining to instrumentation. The Government-Industry Oceanographic Instrumentation Symposium was held August 16-17, 1961, in Washington, D. C., to facilitate communication between Government and Industry. At the meeting were 540 representatives from Industry, 139 representatives from Government, 32 from nonprofit institutions, 22 from the press, 4 from foreign embassies -- a total of 737 attendees.

The importance of the National Oceanographic Program to the Nation was stated by Honorable James H. Wakelin, Jr., Chairman of the Interagency Committee on Oceanography:

"The reason we have turned our attention more seriously than previously to the sea is not a result of recent publicity campaigns, but because of a coordinated look at our program from a number of vantage points, which indicated that during the last thirty years we were not, in effect, giving the proper attention to those areas of oceanography which are both economically and militarily important.

"As you know, the oceans ~~hold~~ both a threat and a safeguard to our security. There is a large, and for the most part, untapped source of protein in the sea that could be used to feed the hungry peoples of the world. Vast mineral treasures may lie in the mysterious mountains of the depths, close and available. Also, the earth's weather is determined in large part by the currents and movements of the sea. It is in our best interest to hold and maintain a world leadership in the development of the oceans for the benefit of all mankind. And, lastly, there is a factor which can never be completely denied: man's quest for knowledge -- the inexorable pull of the unknown.

"All great periods of history have been ushered in by men who moved into new areas and opened new territories. They were led by this same desire, their thirst for knowledge."

The immediate purpose of the National Oceanographic Program is to chart and gain a better understanding of the ocean. We need to map and to understand the ocean bottom, its contents and structure. We need to know the major currents of the oceans, their intensity, their direction, and the major water transport. We need to know more of the basic principles of what controls these movements and of the phenomena of what takes place in the sea.

This static picture might be obtained by an initial overall survey, but it would be only the beginning of what we need to know. The ocean, as a dynamic process, is always changing, and differs from time to time and from season to season. To keep informed of these changes (which are very important for anyone operating in the sea), we have contemplated synoptic surveys to determine what is taking place over a large area at any one particular time. Synoptic data are gathered mainly in three ways: by synoptic survey-vessel surveys, by oceanographic towers, and by buoys.

Synoptic survey vessels are employed principally for gathering data in particular areas or current systems. They may have

other responsibilities but one of their primary missions is to gather oceanographic data.

Towers, fixed platforms placed generally in less than 200 feet of water, are excellent from which to observe phenomena of basic scientific and synoptic survey concern. One of these is Argus Island, located about 30 miles south of Bermuda on top of a sea mount. This is a manned station.

There is a keen interest in the development of special buoys which can gather data from places which ships do not frequent and which are too deep for towers. These are generally anchored in place and have transducers, amplifiers, data storage capacity, and transmitters on them. Dr. William S. Richardson of the Woods Hole Oceanographic Institution has, at present, a string of buoys running from Cape Cod to Bermuda to gather data on currents and temperature. These are rather simple devices when compared with the ones planned, but they have been successful and work now. They are small, toroidal buoys anchored in about 2 miles of water on flexible weightless lines to which are attached instrument pods at different depths. These pods contain sensors, amplifiers, power supplies, and recorders. The anchor lines are pulled up to recover and service the pods and remove the data. Several agencies have plans for gridding large ocean areas with buoys of this and more sophisticated types. Steps are being taken to obtain radio frequencies for monitoring these buoys, by shore stations, ships, airplanes, and possibly by satellites.

To carry out this work, ships will be required: research ships, survey ships, fleet ships, and ships of opportunity. Research ships are those ships whose primary mission is research, investigative in nature. They are highly specialized and carry much equipment which is designed for specific scientific problems. This equipment is often unique since we are finding out what can be done, how to do it, and whether, once a basic problem is solved, more data gathering is desirable.

Survey ships have a primary mission of making rather wide surveys of a predetermined type over a large area, and are move observational in nature, but not entirely so. Their equipments are more standardized for obvious reasons and must be operated and maintained by less highly trained personnel. Better human engineering, more simple designs, and higher reliability are required.

Fleet ships are generally assigned to other problems and missions, but can gather information for synoptic surveys and for surveys in general, on a "not-to-interfere" basis. Equipment for this type of work must be purely operational and very well human engineered.

"Ships of opportunity" are vessels which have a primary mission other than survey or research and cannot compromise their objectives. They might be tankers on a regular run, some fleet ships, fishing vessels, etc. If they are large (i.e., tankers), a special man can be put aboard to use the special equipment. In others a member of the crew can make the observations. Equipment for these vessels must be quite simple and unsophisticated operationally.

Data from research ships, survey ships, fleet ships, ships of opportunity, and all other sources are sent to the National Oceanographic Data Center where they are compiled and put into a form usable for the oceanographic program. They will be made available (at the cost of extraction) to anyone.

The technical aspects and requirements for oceanographic instruments are very important and may be somewhat unique.

In the first place, the final data output of any devices must be compatible with the input requirements of the National Oceanographic Data Center so that it can be easily processed by machine in a reasonable length of time. The importance of prior design planning and good coordination was emphasized by Dr. Woodrow C. Jacobs, Director, National Oceanographic Data Center: "A tape is the obvious storage medium. But this reminds me of the Soviet experience with last year's moon shot. I understand that the coded magnetic and ionispheric data telemetered back from that flight are contained on a tape which is in the order of 400 miles in length and packed with digital information. Furthermore, it seems that the Soviets have found it necessary to edit manually the entire tape -- centimeter by centimeter. And mind you, these are data

from only one space expedition and one which had rather limited scientific objectives. The amount of data gathered on this expedition would be small compared with that of the total oceanographic effort."

The equipment must be reliable and adapted to the ocean environment. Anyone who has served aboard vessels at sea and has tried to maintain new electronic equipment knows that reliability is difficult to achieve. Many unforeseen and, at the time, incomprehensible things take place. Mr. James M. Snodgrass, Scripps Institution of Oceanography, pointed out: "The hazards of environment are well illustrated by an account of mine-eating bacteria. A number of experimental mines were shipped from the east to the west coast for testing in a given environment. These mines had a design life of 6 years. They were planted at various locations in sufficient quantity so that they could be sampled from time to time to determine the effects of the environment. Imagine the chagrin of the experimenters when they picked up their first sample at the end of 6 months and found that the vital parts of the exploder mechanism had disappeared. This was critical. The mine could not have operated, and it probably did not work very long after it was planted. A substantial amount of matter had simply disappeared. In the particular environment tested there dwell a species of sulphide-reducing marine bacteria, anaerobic in their action. They form their own little electrolytic cell and corrode the metal. They work fast. Our Navy colleagues, acquainted with the problems of mothballed ships, are well aware of these troublesome organisms. These things happen and I urge you to exercise all kinds of caution in this regard."

Equipment must be human-engineered so that seasick technicians can operate and maintain it. Equipment should be rugged, very simple to operate and maintain, and accurate enough for the purposes for which it is designed. Long life in an unfriendly environment may be a requirement of instrumentation that is new to some of you. If you plan to make oceanographic instruments, it would be wise to have someone on your staff who has had considerable experience in using them at sea. At the very least, you should have one of your own staff go to sea with your instrument before putting it on the general market. It would be wise to instruct your designers to pay close attention to the observations of your sales engineers who represent the needs and viewpoints of your consumers in this particular instance.

One of the by-products of the Symposium was the Encyclopedia of Oceanographic Instruments. This was begun to obtain some idea of the state-of-the-art and to find out what was available or what had been actually made and used. All companies on our Industry List, as it was in July, and those on the corresponding list of non-industrial scientific laboratories were requested to submit existing descriptions of instruments that had been made and used. Mr. Donald L. McKernan, Chairman of the Symposium and Director of the Bureau of Commercial Fisheries, defined oceanographic instruments as follows: "For the purpose of this Symposium we are considering an oceanographic instrument as, (1) a device used to measure a quantity or quality of the sea, be it physical, chemical, or biological, such as temperature, salinity, density, depth, current, wave motion and direction, radiation, water transparency, light absorption, ambient light, tides, gravity, geomagnetism, or bottom structure or form; (2) an advanced positioning device or a device to collect samples of water, marine plankton, marine fishes, and the bottom including core samples for scientific purposes; or (3) a device for observation and manipulation. Not included are operational devices such as commercial fishing devices, mining devices, such as oil well drilling, and strictly military equipment for detection, identification, classification, or destruction of military objectives. On the other hand, it is recognized that there are a number of kinds of instruments which have an indirect bearing at least on the collection of accurate, precise, oceanographic data. We will be pleased to consider these instruments also."

The response to this inquiry exceeded our expectations. At present, we have a collection of publications, patents, manufacturers' brochures, and processed or typed reports, which is 4 feet thick. They are still being received. One laboratory sent a collection of 66 previously undescribed instruments. We know that the list is far from complete. Attendees at the Symposium from Industry and from the

various agencies of Government were interested in this "encyclopedia." The Panel on Facilities, Equipment, and Instrumentation of ICO appointed an ad hoc Encyclopedia Committee to investigate the possibilities and to take preliminary steps to put this encyclopedia on a more formal and available basis. Specifications were prepared, and the Instrument Society of America was invited to submit a proposal to prepare an encyclopedia and to keep it current, to which all interested parties could subscribe. The Instrument Society is planning to submit such a proposal to define their approach to this problem. Provision was made for an advisory board representing interested Departments of Government, non-industrial laboratories, and Industry.

If your company is interested in investigating the possibilities of manufacturing oceanographic instruments, or of entering the oceanographic field, the following steps would be in order:

(1) Obtain a copy of the Proceedings of the Symposium, which have been covered so very briefly here, from the Miller-Columbian Reporting Service, 931 G Street NW, Washington 1, D. C. This 500-page volume contains:

(a) Verbatim talks by the 22 leading administrators and scientists.

(b) Answers to questions asked and answered at the Symposium.

(c) Answers to questions asked but not answered at the Symposium.

(d) A list of non-industrial scientific laboratories, offices, and interested individuals, including a list of the members of the ICO and its panels.

(e) A list of companies interested in manufacturing oceanographic instruments.

(f) A list of attendees.

(g) Required oceanographic instrument suit for oceanographic survey vessels including estimations of number desired and by whom.

(h) Requirements for oceanographic instrument suit for ships of opportunity.

(i) Requirements for shipboard oceanographic synoptic system for regional and mobile observational networks (ASWEPS).

(j) Lists of instruments needed in fisheries research.

(k) Bibliography of oceanographic publications.

(l) Information on contacting Government contracting agencies.

(m) Biographies of speakers and other participants in the Symposium.

(n) Some abbreviations and acronyms used in oceanography.

(2) Learn as much as possible about oceanography. Start possibly with the bibliography or by adding persons to your staff who have had oceanographic education or experience.

(3) Study your own products to see if they can be adapted for use in oceanography. In many instances, small modifications and changes can be made in existing equipment to apply it to this field.

(4) If you have on-shelf items that appear applicable, it would be wise to try them out in the field with oceanographers.

(5) If you have items that might be adapted, find some oceanographer that is interested and explore the possibilities with him. It would be wise to make contact with reality before putting too much money into something that might not work or that is being handled better in some other way.

If you have the capability and the interest, consider the invitation Dr. William S. Richardson of the Woods Hole Oceanographic Institution made at the close of the Symposium: "Yesterday, Mr. Snodgrass made some remarks that I would very strongly like to second. He suggested that if there are among you people anyone who is serious about learning what the sea and the environment of these instruments is like and who wants to go to sea,

arrangements can be made for you to go to sea on research vessels. I presume he was speaking for his institution, and I think now I can speak for mine. If you want to come as a worker on a trip, we will provide you with a bed and steak lunches and things, and hold your hand if you are seasick. We expect you to work -- not just go along to visit. But arrangements can be made, not always at your convenience, but with some advance planning.

"I would like to leave that thought with you. If you want to go and see what the ocean is like, these arrangements can be made."

The development and manufacturing of oceanographic instruments is not for every company. Many will find that they are not interested or cannot economically embark into it. A serious consideration is urged. Others are already entering the field with considerable vigor. If you pursue a similar course, there will probably be times when you doubt the wisdom of your decision. But in the long run, there will be a number who will do very well, becoming oceanographers in part and instrumentation men in part. If you do this long enough, you will begin to feel that your instrumentation friends do not understand you because you talk too much oceanography, and that your oceanographic friends do not understand you because you talk too much instrumentation. Then you will realize that you, too, have become an interdisciplinarian.

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Made in United States of America
Reprinted from Transactions of the American Fisheries Society
Vol. 92, No. 3, July, 1963
pp. 301–302

Seasonal Occurrence of *Brevoortia patronus* in the Northern Gulf of Mexico[1]

The menhaden purse-seine fishery in the northern Gulf of Mexico depends upon the seasonal appearance of fish schools at the surface and near the coast in spring. In autumn he schools disappear from near-shore waters and apparently move offshore. Efforts to determine the location of menhaden schools in winter have been generally unsuccessful. The southern coast of Florida and the eastern coast of Mexico have been suggested as likely places of winter occurrence (Reintjes and June, 1960). This report gives data on seasonal movements of menhaden in the northern Gulf of Mexico which suggest that the population does not move far offshore in winter.

Locations of occurrence of largescale menhaden, *Brevoortia patronus* Goode, in the Gulf of Mexico were obtained by examining the station records from cruises made by the U. S. Bureau of Commercial Fisheries exploratory vessel *Oregon* over the period May 1950 through April 1962. Additional data were compiled from samples of industrial otter-trawl catches landed between October 1958 and April 1962. Exploratory fishing by the *Oregon* during the 12-year period extended throughout the Gulf of Mexico at stations identified by depth contours ranging from 3 to 2,000 fathoms. Efforts of the industrial otter-trawl fleet were concentrated in the northern Gulf of Mexico in 1 to 30 fathoms. Menhaden were caught with flat, balloon, and midwater trawls, with lampara seines, and with dip nets under light. No attempt has been made to indicate the relative abundance of menhaden at any place or time because of the variety of types and sizes of sampling gear used.

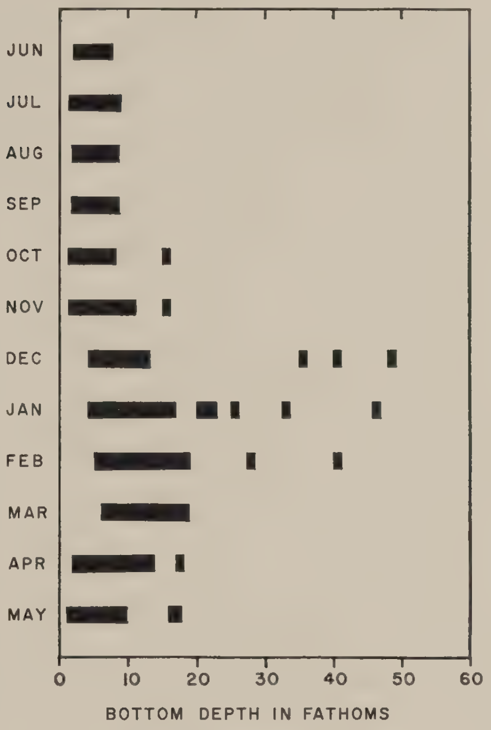

Figure 1.—Offshore distribution of largescale menhaden according to bottom depth at fishing positions of the MV *Oregon* and the industrial trawler fleet, Gulf of Mexico, 1950–62.

Figure 1 shows the monthly occurrence of *B. patronus* according to bottom depth at fishing position from catches by the MV *Oregon* and by the industrial otter-trawl fleet.[2] From June through September, menhaden were present from 1 to 8 fathoms between Aransas Pass, Texas, and the Mississippi River Delta; and east of the Delta between Chandeleur Islands, Louisiana, and Gulf Shores, Alabama. The latter area includes Breton, Chandeleur, and Mississippi Sounds. During October and November, menhaden were taken at depths up to 12 fathoms west of the Delta, and up to 15 fathoms east of the Delta. From December through February, fish were present from 4 to 18 fathoms both east and west of the Delta, as well as over depths ranging from 20 to 48 fathoms within an area 10 to 40 miles east and northeast of the Delta. In March, April, and May, fish occurred from 1 to 17 fathoms between Ship Shoal, Louisiana, and the entrance to Empire Canal, Louisiana; and from 1 to 18 fathoms between Pass a Loutre, Louisiana, and Gulf Shores. No largescale menhaden were caught south of latitude 28° 00′ North.

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[1] Contribution No. 171, U. S. Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas.

[2] Geographical distribution of menhaden in this study is expressed in terms of depth at the positions where sample material was obtained. Fish were actually taken at all levels from the surface to the bottom.

The monthly distribution of largescale menhaden shows a pattern from which movements may be inferred. Beginning in October, an apparent offshore movement from the shallow waters of the northern Gulf of Mexico is indicated. By December some menhaden have moved to the 48-fathom depth range off the Mississippi Delta. Incomplete analysis of length–frequency data suggests that both offshore and inshore fish represent the same population.

The findings in this report lead us to conclude that at least part of the stocks of *B. patronus* winter on the inner and middle continental shelf area just off the Mississippi River Delta over bottom depths ranging from 4 to 48 fathoms. Those fish that are present close to shore in winter probably represent the inshore fringe of the main population. Additional facts which support the view that the bulk of menhaden winter relatively near the summer fishing grounds are: (1) No menhaden have been taken beyond the edge of the continental shelf; and (2) the onset of purse-seine fishing for menhaden in spring takes place nearly simultaneously along some hundreds of miles of coastline, indicating the unlikelihood of local concentrations having traveled any great distance.

If further exploitation of the menhaden resource in the Gulf of Mexico is anticipated, we suggest that increased emphasis be given the accumulation of information concerning winter movements and offshore distribution.

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Made in United States of America
Reprinted from Limnology and Oceanography
Vol. 8, No. 3, July, 1963
pp. 353–355

THE INCIDENCE OF *Malacobdella grossa* IN HARD CLAMS FROM NANTUCKET SOUND, MASSACHUSETTS

The commensal nemertean, *Malacobdella grossa* (O. F. Müller), has a wide distribution along the Atlantic coast, occurring in he bivalve species *Mercenaria mercenaria*, *Mya arenaria* (Coe 1943), and *Mercenaria ampechiensis* (Porter and Chestnut 1960). This nemertean was found in hard clams (*M. mercenaria*) from the shoal water off Monomoy Point in Nantucket Sound, Mass. by Dr. Horace Stunkard (personal communication) and from the deeper water of the ound by Ropes and Martin (1960). The atter observation occurred during a survey of the clam resources in the sound and, alhough the abundance of hard clams was ow, it was possible to detect a differential distribution of this nemertean in various areas.

Samples of clams were obtained with a commercial-sized hydraulic dredge which was towed for 20 min at each station, sampling an area 4 feet (ca. 1.2 m) wide and approximately 2,640 feet (ca. 805 m) long, or about 10,500 square feet (ca. 966 m^2). The locations of 14 subsamples for *Malacobdella grossa*, randomly chosen from the 176 samples that yielded clams during the survey, are shown in Fig. 1. A subsample ncluded 11 or more clams, which were opened and the surface of the soft body mass thoroughly examined. All nemerteans were removed, pressed between glass slides, and fixed in Bouin's fixative. Stained whole mounts were made of several nemerteans to aid identification. The number and percentage frequency of occurrence of *Malacobdella* and the total number of clams opened are presented in Table 1. These data are divided into three areas corresponding to those delineated for the clam survey.

Malacobdella occurred in 6.3% of the clams from the Tuckernuck Shoal area. In the Horseshoe Shoal–Monomoy Point area, where most of the sampling effort for *Malacobdella* was concentrated, 23.5% of the clams contained a nemertean. Only 5.3% of the Edgartown-area clams contained a nemertean. No more than a single nemertean per clam was observed in any of the samples.

Surface water currents may be a factor contributing to the distribution of *Malacobdella* in the hard clams of Nantucket Sound. Experimental observations by Eggers (1936) indicate that the adult nemerteans lack eyespots, do not orient to a stream of water, and are neither attracted nor repelled by possible host bivalves. This suggests that dispersion of the species most likely occurs during the free-swimming, lecithotropic larval phase. The larval phase is apparently of short duration and the larvae appear for only a short time in the surface water (Thorson 1946). Turner (1957) concluded that there was an easterly directed non-tidal drift in the sound. This would tend to transport larvae away from the Edgartown area and is a possible explanation for the observed low nemertean incidence. Conversely, in the Horseshoe Shoal–Monomoy Point area, Turner (1957) reported that slow-moving water

TABLE 1. *The incidence of* Malacobdella grossa *in hard clams from Nantucket Sound, Massachusetts*

Area	Date caught	Station number	Clams examined	Occurrence of *Malacobdella*		
				Number/ sample	Per cent/	
					Sample	Area
Tuckernuck	21 June	1	80	5	6.3	6.3
Horseshoe Shoal–Monomoy Point	25 June	2	40	13	32.5	
	17 July	3	40	2	5.0	
	18 July	4	40	10	25.0	
	18 July	5	40	13	32.5	
	22 July	6	20	6	30.0	
	22 July	7	20	3	15.0	
	23 July	8	20	5	25.0	
	23 July	9	20	7	35.0	
	23 July	10	20	1	5.0	
	23 July	11	20	6	30.0	23.5
Edgartown	14 Aug.	12	25	2	8.0	
	14 Aug.	13	11	0	0.0	
	14 Aug.	14	25	2	8.0	5.3
	Total		421	75		

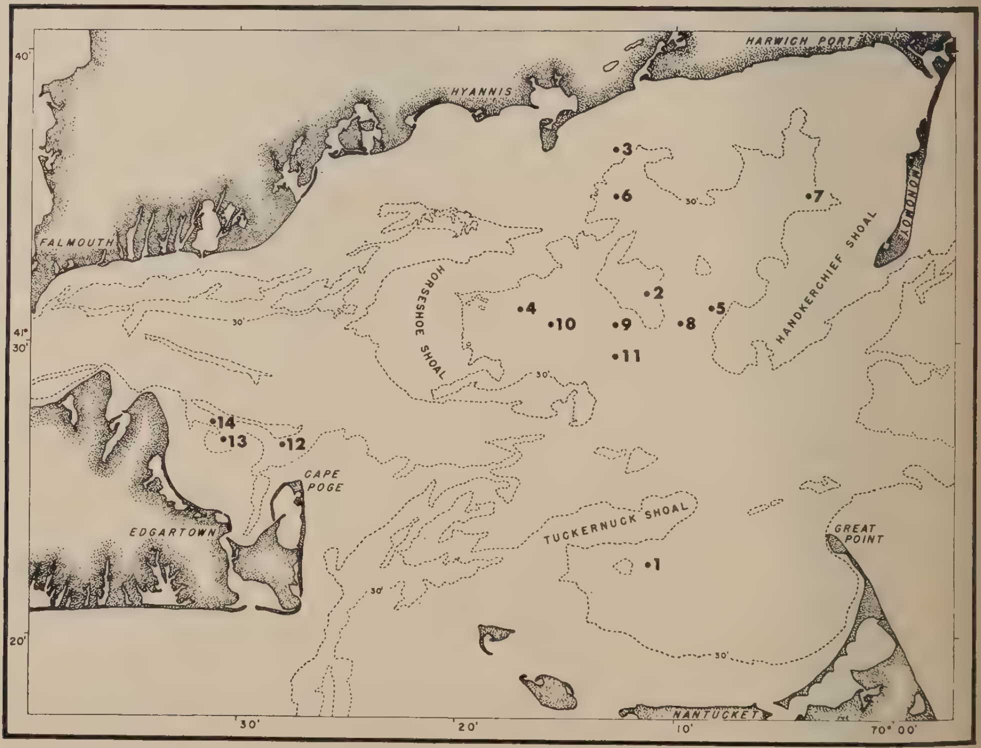
HARWICH PORT
HYANNIS
FALMOUTH
HORSESHOE SHOAL
HANDKERCHIEF SHOAL
MONOMOY
CAPE POGE
EDGARTOWN
TUCKERNUCK SHOAL
GREAT POINT
NANTUCKET
•1
•2
•3
•4
•5
•6
•7
•8
•9
•10
•11
•12
•13
•14
30'
40'
41° 30'
20'
30'
20'
10'
70° 00'

FIG. 1. Sample locations for *Malacobdella* in Nantucket Sound, Mass.

urrents, of less than one mile (1.85 km) er tide, occur to the west of Monomoy oint. This slow-moving water may permit arvae to become established in the bivalves f the area and contribute to the observed igh incidence of *Malacobdella*.

Studies of larval development in relation o environmental conditions and the orienation of larvae to host bivalves are needed o assess the importance of water currents n the dispersion of this species.

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Reprinted from THE PAN-PACIFIC ENTOMOLOGIST
October, 1963 Vol. XXXIX, No. 4—pp. 270-272

SUPPOSED LARVA OF PROTANYDERUS VIPIO (OSTEN SACKEN) DISCOVERED IN CALIFORNIA

(Diptera: Tanyderidae)

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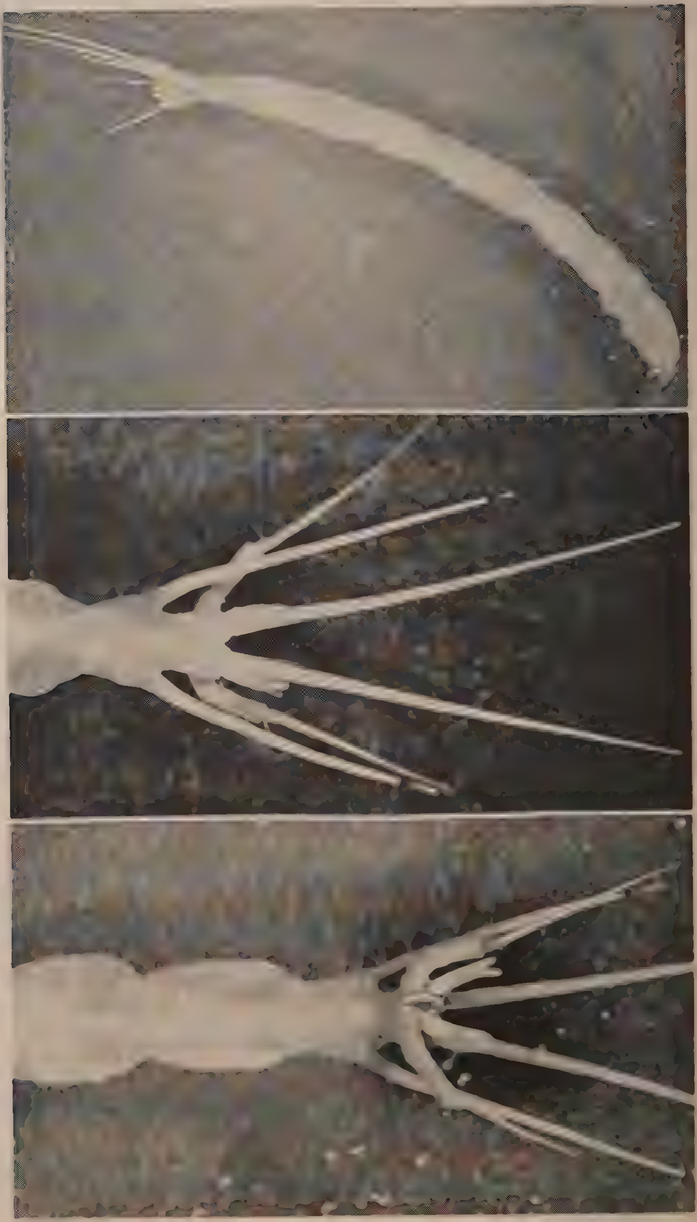
A larva of the primitive crane-fly family, Tanyderidae, has been discovered in Mill Creek, a tributary of the Sacramento River, near Los Molinos, in Tehama County, California. The larva was found in a bottom sample collected in May of 1961. The sample consisted of gravel and silt taken from an area of slow moving water eight to ten inches deep. A search of literature concerning the family has revealed that the immature stages of Tanyderidae have not been reported in California. Adults of two species, however, are found in this state. They are *Protanyderus vanduzeei* Alexander, and *P. vipio* Osten Sacken.

The family comprises 10 genera, with about 35 known species to this date. The only Tanyderidae whose early stages have been

Explanation of Figure

Fig. 1 (Upper), larva of supposed *Protanyderus vipio*, showing complete organism with spiracle on prothorax. 5X. Fig. 2 (Middle), dorsal view of posterior region of larva of supposed *Protanyderus vipio*, showing six filaments and spiracle on eighth abdominal segment. 10X. Fig. 3 (Lower), ventral view of posterior region of larva of supposed *Protanyderus vipio*, showing the two fleshy pseudopods and four anal gills. 10X.



described are *Peringueyomyina barnardi* Alexander in South Africa (Wood, 1952) and *Protoplasa fitchii* Osten Sacken in eastern North America (Alexander, 1930). There are a number of similarities between the Mill Creek larva and those of the above-mentioned species.

Copies of the photographs included in this note were sent to Dr. Charles P. Alexander, Department of Entomology, University of Massachusetts, who unquestionably places the larva in the family Tanyderidae. Based on the geographical location of the collection, and the measurements of the larva, Dr. Alexander confirms the writer's supposition that the larva belongs to the species *Protanyderus vipio*.

Only one larva was found in the Mill Creek sample, and is preserved at the U. S. Bureau of Commercial Fisheries Biological Laboratory, 2725 Montlake Boulevard, Seattle 2, Washington.

Larva.—Length, from head to end of longest filaments, 22 mm. Longest filaments alone, 7 mm. Greatest diameter of body, 2 mm. General coloration, dirty white. *Body* (Fig. 1): Eucephalous; consisting of 12 terete segments, those of the thoracic région shorter and more dilated than those of the abdomen. Posterior end of abdomen with six long filaments, of which one pair is borne near the posterior end of a pair of anal pseudopods. Four simple anal gills. *Head:* A compact, chitinized capsule; antennae very short, apparently three-segmented (mouth parts of this larva damaged, no accurate description). *Thorax:* Prothorax longer than remainnig thoracic segments. Prothorax divided by a constriction into two rings; a small, black spiracle (Fig. 1) on posterior ring near mid-line of bòdy. Mesothorax and metathorax are divided on dorsal surface into two portions by a small constriction. *Abdomen:* Nine abdominal segments that gradually increase in length to the eighth; eighth and ninth decrease rapidly in diameter. Abdominal segments separated by a narrow constriction or ring. Eighth abdominal segment (Fig. 2) with a small black spiracle on side near the posterior margin. Immediately posterior to the spiracle arises a long filament that has a black area near the tip. Ninth abdominal segment (Fig. 3) somewhat shorter than the eighth. From the posterior margin, and on the ventral surface, arise two fleshy pseudopods (Fig. 3), each giving rise to a long filament. *Setae:* Located on dorsal surface and each side of head; a row on each side of body near the ventral-lateral margin; each caudal filament bears from one to three. (A number of setae were broken off of this larva).

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